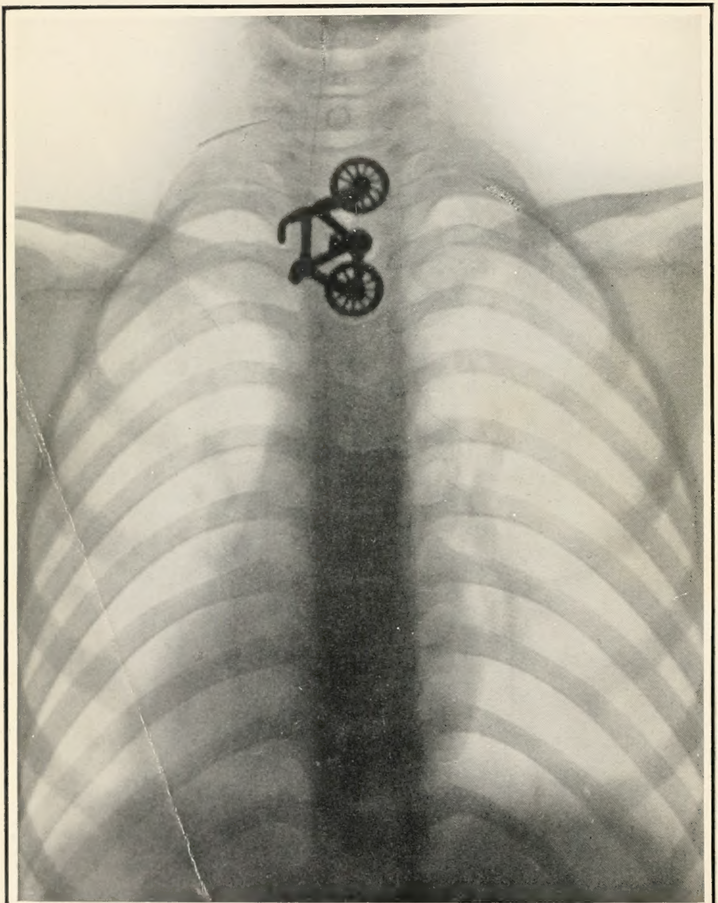
ELECTRICITY OF TO-DAY



By permission of *The London Hospital Authorities*

A Remarkable X-Ray Photograph

A child accidentally swallowed a toy bicycle of considerable size. This was successfully removed at the London Hospital, the surgeons being able to see exactly where the toy had lodged.

(See chap. xxi.)

ELECTRICITY OF TO-DAY

ITS WORK & MYSTERIES DESCRIBED IN NON-TECHNICAL LANGUAGE

By

CHARLES R. GIBSON, A.I.E.E.

Author of

"The Romance of Modern Electricity," etc.

With 39 Illustrations

LONDON

SEELEY AND CO. LIMITED

38 Great Russell Street

1907

BY THE SAME AUTHOR

THE
ROMANCE OF MODERN ELECTRICITY

Describing in non-technical language what is known about Electricity and many of its Interesting Applications

BY

CHARLES R. GIBSON, A.I.E.E.

With thirty-four illustrations and eleven diagrams

"Admirable . . . clear and concise."—*The Graphic.*

"Very entertaining and instructive."—*The Queen.*

"Everywhere Mr. Charles R. Gibson makes admirable use of simple analogies which bespeak the practised lecturer, and bring the matter home without technical detail. The attention is further sustained by a series of surprises. The description of electric units, the volt, the ohm, and especially the ampere, is better than we have found in more pretentious works."—*Academy.*

"Mr. Gibson's style is very unlike the ordinary text-book. It is fresh, and is non-technical. Its facts are strictly scientific, however, and thoroughly up-to-date. If we wish to gain a thorough knowledge of electricity pleasantly and without too much trouble on our own part, we will read Mr. Gibson's 'Romance.'"—*Expository Times.*

PREFACE

WITH the ever-increasing advance in the application of Electricity there has arisen a corresponding demand for a plain account of what is known of this mysterious agent, and of the means by which it is now harnessed and made to do useful work. The success of the author's book on "The Romance of Modern Electricity" has brought him many requests for another work dealing somewhat more thoroughly with the subject, and addressed to a more thoughtful class of readers. He has attempted in the present volume to comply with this request, and, while still avoiding the use of technical language, to treat many subjects of interest which would have been beyond the scope of the former work. In every chapter he has endeavoured to give a trustworthy account of the position which scientific invention has reached to-day; and he has been so fortunate as to obtain the valuable censorship of a number of gentlemen, each of whom is an authority in his own deparment, and has kindly read the proof-sheets of the pages relating to his own subject. The author trusts, therefore, that he has secured

that accuracy of statement without which a volume of this character has no value.

The author is again indebted to Professor Magnus Maclean, D.Sc., M.I.C.E., M.I.E.E., for very kindly reading the whole of the proof-sheets. Thanks are also due to the following gentlemen for kindly reading the proof-sheets of the chapters relating to their special subjects: Professor John G. M'Kendrick, M.D., LL.D., F.R.S., &c. (University of Glasgow); J. Erskine-Murray, D.Sc., F.R.S.E., M.I.E.E. (Consulting Electrician); E. T. Goslin, A.M.I.E.E. (Electrical Engineer to the Glasgow Corporation Tramways); H. Stanley Allen, M.A., B.Sc. (Lecturer on Physics, King's College, University of London); and William Allan, A.M.I.E.E. (Chief Electrician to the National Telephone Company, Glasgow).

In connection with the illustrations, the author is indebted to the following firms, journals, and individuals: Siemens Schuckertwerke, Berlin; Siemens Bros. Ltd.; Dick, Kerr & Co., Ltd.; Bradbury, Agnew & Co., Ltd. (*Punch*); The Commercial Cable Company; Institution of Electrical Engineers; The London Hospital authorities; Lieut.-Colonel H. C. L. Holden, R.A., F.R.S.; Dr. John Evan Spicer; John J. Webster, London; *The Scientific American*, New York; *The Electrical Magazine*, *The Engineering Magazine*, *Popular Electricity*, London; Lord Armstrong, New-

castle-on-Tyne ; Alex. Thomson, Paisley ; Mavor and Coulson, Ltd. ; The Holland House Electrical Manufacturing Co., Ltd. ; Charles Stewart, Alex. M'Grouther, and John Trotter, Glasgow.

The author is also indebted to Baird & Tatlock, Glasgow, for particulars of their automatic fire-alarm ; to Miss E. L. Seeley, for the account of the damage done to Barsham Church by lightning ; and to Henry A. Mavor, for particulars of the remarkable case of accident by lightning experienced by a Tyneside engineer.

CONTENTS

CHAPTER I

PAGE

INTRODUCTION 15

CHAPTER II

ELECTRICITY AS A MOTIVE POWER . . . 29

CHAPTER III

ELECTRIC TRACTION 43

CHAPTER IV

A LARGE TRAMWAY UNDERTAKING . . . 56

CHAPTER V

MORE ABOUT TRAMWAYS, RAILWAYS, &C.. . 66

CHAPTER VI

ELECTRICITY AS AN ILLUMINANT . . . 76

Contents

CHAPTER VII

PAGE

Electric Heating and Cooking . . . 98

CHAPTER VIII

Electro-Chemistry 111

CHAPTER IX

Electricity from Heat 132

CHAPTER X

Electric Meteorology 140

CHAPTER XI

More about Lightning, &c. 154

CHAPTER XII

Lighter Duties of Electricity . . . 166

CHAPTER XIII

Telegraphy by Land 183

CHAPTER XIV

Telegraphy by Sea 204

Contents

CHAPTER XV

PAGE

Telegraphing without Wires . . . 215

CHAPTER XVI

Electrical Transmission of Speech . . 239

CHAPTER XVII

More about Telephones 254

CHAPTER XVIII

Some Interesting Experiments . . . 264

CHAPTER XIX

Electrical Measurements 271

CHAPTER XX

Electricity Meters, &c. 289

CHAPTER XXI

Medical Applications 294

CHAPTER XXII

Positive and Negative Electricity, &c. . 303

Contents

CHAPTER XXIII

PAGE

PRESENT IDEAS OF ELECTRICITY . . . 317

CHAPTER XXIV

CONCLUSION 331

APPENDIX I. 334

APPENDIX II. 339

INDEX 345

LIST OF ILLUSTRATIONS

A Remarkable X-ray Photograph . .	*Frontispiece*	
An Electric Current affects a Magnet (2 Illus.)	*To face page*	18
A Complete Electric Circuit (2 Illus.)	,, ,,	28
(1) A Large Dynamo. (2) A Simple Dynamo	,, ,,	42
(1) A Modern Tramway Car. (2) Tramway Cars in Use . . .	,, ,,	56
The First Public Electric Railway .	,, ,,	66
A Test Race	,, ,,	74
An Electrically-driven Fire-Escape (2 Illus.)	,, ,,	86
An Electric Kettle in the Drawing-Room	,, ,,	98
The Production of Diamonds by the Electric Furnace	,, ,,	110
Water Decomposed by Electricity (2 Illus.)	,, ,,	128
Strange Result of Lightning in a Church	,, ,,	154
(1) Poker lifting Scissors, &c. (2) Magnet lifting Projectiles . .	,, ,,	166
A Handy Electric Tool . . .	,, ,,	182
Landing the Shore End of an Atlantic Cable	,, ,,	204
An Aerial Ferry	,, ,,	214

List of Illustrations

An Electric Elevator for Ocean Liners (2 Illus.)	*To face page*	238
Designs Produced by a Vibrating Plate (4 Illus.)	" "	244
Chicago Underground Goods Railway	" "	256
The Autograph of an Electric Spark (2 Illus.)	" "	270
(1) A Radiometer. (2) A Rotating Egg-Shell	" "	288
A Large Electro-magnet (2 Illus.) .	" "	302
Taking an X-ray Photograph (2 Illus.)	" "	314
Baby Electricity: "What will he Grow to?"	" "	332

ELECTRICITY OF TO-DAY

CHAPTER I

INTRODUCTION

Do we know what electricity is?—The first electrical experiment on earth—A very celebrated physician—The meaning of conductors and insulators — A curious experience of electric shock—Early electrical machines—An all-important debate between two Italian professors—The evolution of the battery —The discovery of magnetism—Intimate connection between magnetism and electricity—The principle of the dynamo discovered—Some remarks about magnets—A coil of copper wire becomes a magnet—Electro-magnets—Why an electric current requires a complete circuit

NOT so very long ago the average man was content to know that such instruments as the telegraph and telephone were "just worked by electricity," but now that electricity has come so much to the front in our everyday life, there are many persons who do not feel satisfied with such a vague idea. The advent of electric traction has caused many to wonder by what means electricity is harnessed, and made to propel a tramway car or railway train.

One sometimes hears people say, it is ridiculous that electricians can make use of electricity, and yet not know what it is; but when we wind up a grand-

father's clock, and cause the falling weights to drive the mechanism, are we not making use of gravity, of the nature of which we seem at present to be hopelessly ignorant? To say that we do not know what electricity is, is still true, but our knowledge of its nature is very different to-day from the ideas of a generation ago. It will certainly be of interest to know what scientists have to say regarding the nature of electricity, but I shall leave that to a later chapter. We shall see that electricity, light, and radiant heat, are all of the same nature, but we have sense organs responding to light and heat, whereas electricity does not directly affect any of our sensory organs. We therefore do not require to use such artificial language in speaking of light and heat, as we are forced to do in connection with electricity.

For our present purpose we need not trouble about exact historical facts and dates, but it will be of interest to trace how electricity has come into our everyday life. To make matters as brief and as clear as possible, I shall only deal at present with the main facts.

If I briskly rub the handle of my fountain-pen against my coat-sleeve, and then bring it near to any small pieces of paper, I shall find that the paper is attracted towards the pen-holder. This peculiar attractive power was observed more than two thousand years ago, for it was then known that when a piece of amber was rubbed on a woollen cloth, it would attract small pieces of straw or woody fibre. The unknown ancient philosopher who first observed this simple phenomenon, undoubtedly performed the first electrical experiment upon this earth,

and although this discovery did not seem to be of any consequence to man, its very strangeness would keep it alive for generation after generation. The illustrious Pliny is reported to have offered as an explanation of this experiment, "that friction gave the amber heat and life."

For century after century amber got credit for possessing some special power, so much so that no one seems to have tried by simple experiment if any other substance would give the same result, until one of Queen Elizabeth's physicians set about making a series of systematic experiments. This famous man, Dr. William Gilbert, of Colchester, found that glass, sulphur, resin, and other substances possessed the very same attractive property as amber. However, as this property had first of all been observed in amber, Dr. Gilbert suggested the name "electricity," from the Greek word for amber (*elektron*), and so we call the attractive property electrical attraction, saying that the amber is electrified, and so on. As time went on many other substances were added to the list, until it was recognised that this property was, in some measure, common to all bodies. By experiment we find that some bodies exhibit the attractive property better than others. A favourite method is to rub a piece of vulcanite (a composition of india-rubber and sulphur) against a cat-skin or flannel, while another is to "excite" a glass rod with a piece of silk cloth.

If simple friction between two different substances produces this electrification, why do we not continually see evidences of this electricity around us? A very simple experiment will explain the matter,

for if we take a piece of metal we may rub and rub this with the cat-skin or flannel, and we shall find no signs of electrification. If, however, we fix the metal rod on to a glass handle, we shall find that it answers just as the vulcanite rod did. The only reasonable explanation is, that while we held the metal in our hand the electricity escaped away by us to the earth as quickly as it was produced, but when we held it by the glass handle the electricity was prevented from thus escaping, and therefore the metal rod became electrified. It is natural to ask how, when the glass and vulcanite rods were electrified, the electricity did not also escape by the hand that held them. It would do so if one touched the electrified part, but it is just as though one was holding the glass rod by a glass handle, part of the glass acting as a handle to the other part, for we find the electrification to be only on that part of the rod where the rubbing took place, whereas in the case of the metal rod the electricity spreads along the whole length. It was, therefore, early recognised that some bodies conducted electricity, while others seemed to act as non-conductors or insulators.

It therefore comes about that, in everyday life, we seldom see signs of electricity being produced by one substance rubbing against another, as the electricity is so easily conducted away to the earth and dissipated. One does occasionally see such manifestations, and I think one of the most striking which I have witnessed was in a textile factory, when some long pieces of woollen dress goods were being drawn over a large wooden table, and allowed to fall in a heap upon the floor. On a dry day I have seen a man go

1

2

AN ELECTRIC CURRENT AFFECTS A MAGNET

1. Arranging the experiment.

2. While the current is passing through the coil of copper wire it acts exactly like an ordinary magnet; one face being a north and the other face a south pole. This illustration shows the one face or pole of the coil attracting the dissimilar pole of the magnetic needle. This simple discovery has led to the great applications of electricity of the present day.

(See page 22.)

forward to lift the goods and receive quite a surprising electric shock.

It was natural that, when men came to interest themselves in this mysterious electricity, they should make simple machines to do the rubbing on a larger scale than could be done by hand. In one of these primitive electrical machines a glass cylinder is revolved and made to rub against a leather cushion, the electricity being collected by means of a metal conductor having fine points placed in close proximity to the glass cylinder. By such machines an electric spark was produced, and many interesting experiments were performed ; but as electricity produced by this means is of chief interest in the scientific laboratory, I shall not deal with it at present. The purpose of mentioning it here is merely to explain how our present knowledge was attained.

It was when experimenting with one of these machines, about the close of the eighteenth century, that Professor Galvani, of Bologna, observed that the legs of a freshly killed frog were convulsed by an electric discharge. It seems to have occurred to Galvani to try if a lightning discharge would have the same result, and he was about to suspend the frog's legs by a copper skewer to the iron railing on the balcony of his house, when he observed the twitching to take place as soon as he placed the copper skewer in contact with the iron railing. Galvani jumped to the conclusion that the animal tissue contained electricity, that the brain secreted it, and that it was communicated to the body by the nerves, while the muscles acted as reservoirs.

Another Italian professor, Alexander Volta, of Pavia, repeated Galvani's experiments; but he declared that the electricity did not reside in the animal tissue, but was produced by the contact of the two pieces of dissimilar metals—the copper skewer and the iron railing. A very profitable discussion took place between these two celebrated philosophers, but Volta was soon able to prove his contention to be correct. He made up a pile of discs of copper and zinc, placing between each pair a piece of cloth moistened with acidulated water (a few drops of sulphuric acid in water). After building up a pile with a number of pairs or couples arranged as described, Volta connected a wire to the zinc disc at the top of the pile, and another wire to the copper disc at the bottom; and when he brought the free ends of the two wires together, he was able to show an electric spark on again separating the wires. This amply proved Volta's point that the electricity was not in the frog's tissue.

The pieces of moistened cloth in Volta's pile soon dried up, thus interfering with its action, and this led Volta to immerse each pair of copper and zinc pieces in a separate vessel filled with acidulated water. This new arrangement greatly enhanced the effect. A number of such chemical cells connected together was called a battery, signifying a battery of cells, but nowadays one often hears a single cell called a battery. Our present batteries are all merely modifications of Volta's early chemical cell.

There was such a marked difference in the behaviour of the electricity produced by these voltaic cells and that obtained from the frictional machines, that their identity was doubted for more than a generation, so

that the one was designated "frictional," and the other "voltaic" electricity.

When a body was electrified by one of these frictional machines, the charge dissipated with lightning suddenness the instant a way of escape to earth was provided. On the other hand, the electrical effect produced by the chemical battery was so very different, continuing to flow quietly along a connecting wire, that it was picturesquely named "the electric current," which term has become a household word with us.

Turning for a moment to consider how magnetism became known, we find it a long look back in the world's history to the discovery of a peculiar stone, or iron ore, which it was observed would attract small pieces of iron to it, and would pass on its attractive power to pieces of iron without any appreciable loss to itself. It was further observed that when an oblong piece of this stone was freely suspended, it would always come to rest in a definite position, one end pointing in the direction of the north pole of the earth, and the other, of course, pointing southward. The utility of this directive property was very early recognised, and made use of by travellers when crossing the deserts, the stone receiving the name of leading-stone or lodestone.

Steel magnets were well known at the time of Volta's discovery of the electric current, and very soon it was observed that an intimate connection existed between magnetism and electricity. This discovery has been of immense value to us, for when a Danish professor, early in the nineteenth century, observed that a small magnet or compass needle

was affected by an electric current passing in a neighbouring wire, he discovered the fundamental principle upon which nearly all modern applications of electricity have been built up. What Oersted, the Danish philosopher, did find was simply that, if a wire was stretched over or under a magnetic needle, the magnet would turn round and take up a position at right angles to the wire. The effect was enhanced if, instead of using a single wire, a long wire was coiled up, so that the current would pass round and round in the neighbourhood of the magnet (see illustration at p. 18). The movement of the magnet produced in this way has given us telegraphs, electric bells, &c., and it is this very turning power which drives our electric railway trains and tramway cars.

About a dozen years later it was discovered by our illustrious Faraday, while experimenting in the Royal Institution (London), that the converse of this action between an electric current and a magnet was also true, for he found that if a coil of wire was quickly moved in the neighbourhood of a magnet, an electric current was generated in the moving coil. Here indeed was a crowning discovery, for it gave us the principle of the dynamo, the advent of which has made it possible to produce electric currents on a large scale at a small cost.

We have now seen the very simple experiment with rubbed amber lead up to the construction of "frictional machines." Then it was observed that these machines produced a certain twitching effect in a frog's legs, and that the same movement resulted if they were touched by two pieces of dissimilar

metals in contact with each other. From this simple discovery the "battery" was evolved. Then, commencing with the lodestone or natural magnet, found in many parts of the earth, we find the intimate connection between electricity and magnetism experimentally discovered, and we are now in a position to follow the great modern development of these simple but all-important discoveries.

I have purposely made this introductory chapter very brief, and therefore incomplete, but it will be understood that I have here only touched upon those points which seemed to me essential by way of introduction, leaving the rest to fall into the chapters to which they more particularly relate. It would be well, however, to make one or two properties of magnetism and electricity quite clear at the outset.

If we take a straight bar of steel which has been magnetised, we find one of its ends or "poles" marked with the letter N, signifying that the magnet would turn this end towards the north pole of the earth, when freely suspended or supported so that it could revolve upon its centre. Seeing that one end invariably turns northwards and the other southwards, it is only logical to suppose that there must be some difference between the two ends. We find by simple experiment that each end attracts iron equally well, so that there is no difference in their attractive powers, but if we take two straight bar magnets we find a very interesting phenomenon. Each has one end marked N, signifying the north-seeking pole, but more shortly called the north pole of the magnet, the other end being called the south pole. On bringing the north pole of the one magnet towards the

south pole of the other, we find a powerful attraction, but if we bring one north pole towards the other north pole, we find no attraction whatever, and on trying the two south poles together, we find they also will have nothing to do with each other. We shall see this better still if, for one of the magnets, we use a large compass needle delicately balanced on a pivot at its centre. We now bring the north pole of a bar magnet near the north pole of the compass needle, and we find not only no attraction but a very decided repulsion, for the latter turns away its north pole, and if we follow up its retreat with the bar magnet, the compass needle will always keep at a respectful distance. The moment we turn the south pole of the bar magnet towards it, it is forcibly attracted. In this simple way we can demonstrate the very important fact that, while either pole of a magnet is equally attractive to iron or steel, the two magnets behave very differently towards one another. A north pole and a south pole will always attract each other, but the north poles repel one another, as also do the south poles.

We have already seen that when an electric current passes along a wire, there is an effect produced quite outside of the wire, for a magnet placed in its neighbourhood will turn round at right angles to the wire. Has the electric current then some magnetic force? Certainly it has, and we can very easily demonstrate this by a simple experiment. In order to get as big an effect as possible, we shall coil the wire up into a small circle or rectangle, and as we wish the current to go round the whole length of the coil, we must take a wire with some insulating covering, to prevent

the current taking a short cut across from the leading-in to the leading-out end of the coil, without troubling to pass through the length of the wire. We make the coil as light as possible, by using a very fine copper wire covered with silk yarn wound round and round the wire. We then suspend the coil, so that it may be freely moved to and fro, and having connected the ends of the coil to a battery, we send an electric current through the coil. We then bring the north pole of a bar magnet near the face of the coil, and we find that the coil is attracted, just as though it was a steel magnet. We then present the same pole of the magnet to the other face, or back of the coil, and we find it is repelled, so that there is not the slightest doubt that this coil of copper wire, with an electric current, is like a magnet, having one face a north pole, and the other a south pole. This is of immense practical value to us, for here we have a magnet completely under our control. The moment we send a current through the coil it becomes a magnet, but immediately we stop the current, the magnetism disappears. We further find that we can make the poles change places at will, for if we send the current in at one end of the coil, the north pole appears at the front face of the coil, but if we reverse our connections to the battery, and send the current through in the opposite direction, we find the south pole at the front face, and the north now at the back. We have therefore a magnet which we can make powerful or weak according to the amount of current we send through the coil, and we can also change the position of its two poles at will.

If we place a rod of soft iron in the coil, so that

it forms a core to the surrounding coil, which does not necessarily touch it, we find that we have a much more powerful attraction, as though the iron had concentrated all the attractive power which surrounds the wire. The iron will now lift a considerable weight, but the moment the current ceases in the surrounding coil, the iron lets go its burden. A coil of wire with a soft iron core is called an electro-magnet, and is under complete control. If we wind a length of insulated wire around a kitchen poker and attach the ends of the wire to a battery, the poker will immediately become a magnet. If we use a bar of hard steel in place of iron, we shall find it more difficult to magnetise, but when once magnetised it will remain so, after the controlling current has been withdrawn. While artificial magnets were originally made by stroking the metal with a piece of lodestone, they are now manufactured just in the way we magnetised the poker, and if made of steel so that they retain the magnetism, they are called permanent magnets, in contradistinction to the electro-magnets which are temporary.

There is one point in connection with the insulation of wires, which may be remarked on here. If wires are to be placed in contact with each other, or to be touching any other conductor of electricity, it is necessary to incase them completely with some non-conducting material, such as cotton, silk, or rubber. Insulation does not necessarily mean that the wire is thus enclosed, for the bare overhead telegraph wire is insulated by being supported on pieces of porcelain, which, being non-conductors, do not allow the electric current to escape to earth.

Introduction

The meaning of an electric circuit is to many persons a mystery, and even to connect up a bell, battery, and push, seems to be to some people a difficult operation. There is no reason why this should be so, for all we have to do is to provide a path for the current through each piece of apparatus. I remember that as a boy I formed the habit of always picturing electricity as a very "fly" customer, for it would keep its eyes open for every short cut, and it would never go a roundabout way, unless it was left no option in the matter. To take the case of a bell, battery, and push, we see at page 28 the different parts of the battery or cell. In the right hand, in the first illustration, is seen a carbon cylinder, and in the other hand a rod of zinc, these two elements being connected by a wire. When these elements are immersed in a solution of sal-ammoniac, contained in the glass jar seen upon the table, a current of electricity flows along the wire from the carbon to the zinc, and on reaching the zinc we may imagine it passing through the liquid to the carbon, and again along the connecting wire, and so on; the battery acting as an imaginary pump. We cut the wire and connect the ends to the bell terminals, as shown, so that the current must now pass round an electro-magnet in the bell, the mechanism of which will be described in a later chapter. The bell would now ring, and continue ringing as long as it is thus connected, but if we cut the connecting wire at any place, the bell immediately stops ringing, as the current has no path left. We now connect the broken ends to the "push," which, in its normal position, still gives the

current no path, but which, when pressed, makes a metallic contact between the ends of the wires, picturesquely acting just as a drawbridge. As long as the circuit is kept closed by pressing the push, the current gets through to the bell, but as soon as the push is released the circuit is again broken. It is therefore clear that we always require a complete circuit for a current of electricity. Perhaps the clearest view is got by picturing the current trying to get across from the top of the carbon to the top of the zinc in the cell, and in allowing it to do so we may provide quite a long path, forcing it to pass through our apparatus on its way.

The important points which we must particularly bear in mind, are those relating to the intimate connection between electricity and magnetism, for in the following chapters we shall see what a great number of the practical applications of electricity are entirely dependent upon this relationship.

1

2

A Complete Electric Circuit

1. The electric current flows through the wire from the carbon cylinder, in the right hand, to the zinc rod, in the left hand, whenever these elements are immersed in the solution contained in the glass jar.

2. In order to get from the carbon to the zinc the current has now to pass through the bell and push and then to the zinc. The meaning of a complete electric circuit is apparent.

(See page 27.)

CHAPTER II

ELECTRICITY AS A MOTIVE POWER

What makes the motor go?—The source of energy—General aspect of a power station—A simple experiment which led to great things—Dynamos and motors—Modern dynamos—How the dynamo gets its magnetism—A descriptive analogy—First ideas—A summary

Of all the practical applications of electricity, the most bewildering to the uninitiated is doubtless its motive power, as seen in the driving of electric tramway cars or railway trains. These are driven by electricity, but how can they receive propelling power from mere contact with a stationary trolley wire or rail, and, in short, "what is it makes the business go?"

The propelling power of a steam-engine is easily grasped, as every one appreciates the expanding force of steam, but electricity is so different. I have found the mystery very greatly increased in the minds of some people, owing to their not being aware that an electric motor is fixed underneath the car or train.

It may simplify matters to look first of all at a stationary motor, fixed in some building where it is driving machinery, but even then there is an atmosphere of mystery. We see some iron castings wrapped around with simple coils of wire, mounted up in a particular manner; one part of the machine is spinning round at a great speed, and from the clatter of the machinery which it is driving, it is

quite apparent that this motor is a very powerful engine. The electrician merely turns a switch, and off the motor goes. It is clear that pieces of iron and coils of wire cannot of themselves develop power, so we must look for the source of energy outside of the motor itself. The motor's only possible connection with any source of power is through two stationary wires, so we cannot do better than follow these. We find that as they leave the workshop the wires go underground, and when we are shown their other ends, we find them leading into an electric power station, possibly at some considerable distance from the workshop in which we saw the motor. In the power station we find the wires attached to a machine identical in appearance to the motor itself, having one part spinning round, but in this machine the revolving part is being driven round by a powerful steam-engine. We can now trace the source of energy, for in an adjoining building we see the large furnaces and boilers producing steam, which is conducted by pipes to the cylinders of the steam-engine.

Before leaving the power station we learn that the machine, which the engine is driving, is called a dynamo, from the Greek word *dynamis*, meaning force, and we are also informed that the part of the dynamo which is being made to spin round is called the armature. We further learn that this revolving armature is generating an electric current, which is being conducted along the wires, or underground cables, to the distant workshop, and that there the wires are connected to the armature of the motor, which commences to spin round as soon as the current passes through it.

We have therefore a source of power at the generating station producing electric currents by means of a dynamo, which sends on the electricity to a distant motor, causing its armature to spin round. It only remains to fix a drum or "pulley" on the end of the armature shaft, and another on the shaft of any machine, and then to carry a leather belt over the two drums, so that when the armature revolves it will cause the shaft of the machinery also to turn round. If there are a number of machines to be driven, we can drive a long steel rod or "shaft," from which we can connect leather belts to each machine.

To understand what is really taking place, we may go in imagination to the scientific laboratory of the Royal Institution (London), in which the late Michael Faraday discovered the great principles upon which dynamos and motors have been constructed; where, in fact, Faraday laid the foundation stones for electrical engineering. In this laboratory Faraday observed that when he moved a coil of insulated wire in the immediate neighbourhood of a magnet there was a feeble current of electricity generated in the coil. This he could tell by having in circuit with his coil, a delicate instrument wherein an indicator would move if any electricity passed through the instrument. Faraday soon noticed that this current was only generated when he caused the coil to enter the sphere of influence, or, in other words, the magnetic field, and again when he withdrew the coil, but no effect was produced as long as the coil remained stationary in the field. Faraday's imaginative mind suggested that the space between the poles of the

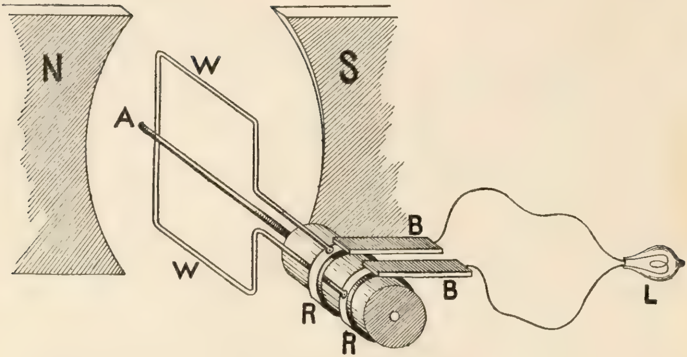


DIAGRAM I

THE PRINCIPLE OF A DYNAMO, SUPPLYING ALTERNATING CURRENT

N and S = North and south poles of magnet.

W W = Rectangular loop or coil of wire.

A = Spindle for above to revolve upon.

W and A together are called the armature.

(When revolved in the magnetic field an electric current is produced in the coil W W, the current changing its direction at each half revolution.)

R R = Two metal rings ; one fixed to each end of coil W W.

B B = Brushes which press against the revolving rings and thus make connection between the revolving coil and the outer or main circuit.

L = A lamp in the main circuit.

(The current in the main circuit will, of course, alternate in direction just as in the revolving coil.)

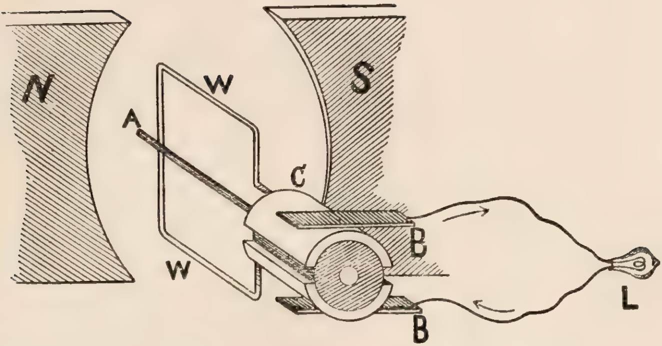


DIAGRAM II

THE PRINCIPLE OF A DYNAMO, SUPPLYING DIRECT OR CONTINUOUS CURRENT

N and S = North and south poles of magnet.

W W = Rectangular loop or coil of wire.

A = Spindle for above to revolve upon.

W and A together are called the armature.

(When revolved in the magnetic field, an electric current is produced in the coil W W, the current changing its direction at each half revolution.)

C = Two bent metal contact pieces to which the two ends of W are fixed.

B B = Brushes which press against the revolving contact pieces and make connection to the main circuit.

L = A lamp in the main circuit.

(Instead of leading out the alternating current from the revolving coil, it is led out all in one direction, as indicated by the arrows, and as explained in the text.)

magnet was filled with "lines of force," and that it was when the loops or coils of wire passed through or "cut" these lines of force that the current was originated in the wire. It soon became clear, therefore, that the oftener the coil cut these lines of force, the better effect would be produced, and so it was suggested to mount the coil of wire on a bobbin or spindle, and quickly revolve it in the magnetic field.

When these facts became known, people set about making up small machines in which a bobbin of wire could be revolved by hand, so that it successively entered and left the magnetic field produced by a permanent magnet, and thus generated an electric current in the moving coil. Faraday had already pointed out, that his indicating instrument showed that, when the coil was being withdrawn from the magnetic field, the current was in the opposite direction to that produced when it entered the field, so that as the coil revolved it had a pulsating current, first flowing in one direction and then in the other, changing at each half revolution. A to-and-fro current of this kind is called an alternate or alternating current.

When Faraday made his great discovery, he did not sit down and design a dynamo; that is not in the order of things. It was only natural that a long period of evolution had to be passed through before a practical dynamo was produced. It would be interesting to trace the different steps taken during the following generation, but as historical facts and dates are wearisome to some readers, I shall merely mention the main steps achieved, and more particular details will be given in an appendix at the end of the

book. The first difficulty that appeals to one is, how to lead the current away from the moving coil. It is quite evident that we cannot attach wires directly to the moving coil, as they would immediately be twisted round and round and broken off. It is fortunate, however, that in order to make electrical communication complete, we do not require to have one wire soldered or welded to another; it is quite sufficient if the one wire touches the other. We therefore take the one end of the movable coil of wire, and attach it to a metal ring which we fix on the end of the armature shaft or spindle, so that this ring will revolve with the coil. We then fix the other end of the coil to a similar ring which we place alongside of the other, but taking care to insulate the rings from each other, and from the metal shaft. Instead of having the two loose ends of the coil to deal with, we now have two complete rings on the armature shaft, and it is quite an easy matter to arrange that two stationary wires be kept in contact with these rings, and thus lead away the current generated by the moving coil.

In order to collect the current conveniently from the revolving coil, a bracket may be arranged to hold a piece of metal against one of the rings, so that, as the armature spindle turns round, this metal piece or "brush" rubs against the ring, always keeping in contact with it. A similar brush is arranged to keep in contact with the other ring (Diagram I). We can now carry a wire from one of those stationary brushes to an electric lamp and back to the other brush, thus making a complete circuit through which the generated electric current will flow. This stationary

circuit has become, in fact, a part of the coil. We have, as it were, stretched out a long loop from the coil; and, so that this loop or circuit may remain stationary, we have cut the wires, but by means of the rings and brushes we still keep a continuous path for the current throughout the whole circuit. In modern dynamos the brushes are metal holders with blocks of carbon pressing on the metal rings, which arrangement gives a much better rubbing contact than is possible between two pieces of metal, producing less sparking. It is clear that we may now drive the armature round by means of a steam engine, a water turbine, or any other source of power, and no matter how quickly we cause the armature to rotate, the outer circuit is always in contact with the coil of the revolving armature.

So far we have imagined the coil to be spinning round between the poles of a permanent steel magnet, but if we replace this by a large electro-magnet, such as is described in the preceding chapter, we shall be able to get a more powerful magnetic field, or we may picture it as an increased number of lines of force, and we therefore get a greater current generated in the armature and the outer circuit. But from whence are we to get the electric current for energising the large electro-magnet? We may connect it to a large battery, but that will prove expensive and not very satisfactory. We might steal some of the generated current from the circuit itself, and pass this round the magnet, but unfortunately this current is continually changing its direction, and this would continually change the poles of the electro-magnet, which would be quite impracticable. If we could

cause the current to flow all in one direction, then we could use it for energising the magnets. It is clear that we cannot prevent the current in the moving coil being alternately in the one direction and then in the other, as its direction must alter at each half revolution; the current being set up in one direction as the coil approaches the north pole of the magnet, and in the opposite direction as it leaves this pole and is approaching the south pole. We must therefore leave the to-and-fro current in the armature coil as it is, and see what can be done with the outer stationary circuit. As long as the one brush is kept in contact with the same ring (*i.e.* the one end of the coil) and the other brush is kept to the other end of the coil, then we are bound to have the same alternating current in the outer circuit as we have in the moving coil; but if we could make the brushes change partners every time the current altered in direction, then we should have a current in the outer circuit all in the one direction.

By way of analogy let us imagine a length of water-pipe with its two ends open, while there is a pump in connection with the pipe, so arranged that at its first stroke it sends the water out at No. 1 end, and at the second stroke from No. 2 end, and so on alternately. If we take a short length of flexible hose-pipe, and with this join the ends of the pump-pipe together, we shall then have water flowing through this hose-pipe first in one direction and then in the other, to which we may liken the alternating current of electricity. In imagination I now listen till I get the beat of the pump, as it were, in my ear, and then taking the two ends of the hose-pipe in my

hands, I make its ends change places at each stroke. The end which I hold in my right hand was at the first stroke receiving water from No. 1 end of the pump-pipe, and at the second stroke I had moved it over to No. 2 end, just as the pump discharged from that end, once more moving it back to No. 1 end in time to receive the water as it was discharged there. In this way I can have the right-hand end of the hose always feeding in, while the other end is always feeding out. It will be clear that, although the water in the pump-pipe is changing direction at each stroke, the flow in the hose-pipe, or outer circuit, is all in one direction. We must do something similar with the dynamo in order to convert, or commute, the alternating current of the moving coil into a uni-directional current in the outer circuit; and it can be done.

If we now picture the dynamo as an electric pump, we notice that our water-pump analogy is not "true to life," for it was discharging its water current alternately from two fixed or stationary points, whereas the armature coil is discharging its electric current alternately from two moving points, the ends of its coil being in continual rotation. This, however, is most convenient, for as we have the two discharging ends in motion, we are saved the trouble of moving the ends of the outer circuit, as was necessary in the water-pump arrangement. We have only to arrange that the two ends of the moving coil shall alternately touch one stationary brush and then the other. This may be very easily accomplished, for if we fasten each end of the coil to a half ring in place of a complete ring, and then put these two

semicircular pieces on the spindle, just as though we were about to join them together to make up a complete ring, but in reality taking good care to insulate the one from the other and from the spindle or shaft, we may then place the brushes in the same plane or line with each other, so that as the armature spindle revolves the brushes will touch each half ring alternately (Diagram II). While No. 1 end of the revolving coil is discharging its current it will be in contact with the top brush, and at the next half revolution, when it is feeding-in, it will be touching the bottom brush, while the other end of the coil will be doing exactly the reverse. Therefore we may picture the top brush to be always acting as the inlet for the outer circuit, and the bottom brush to be invariably its outlet, so that the current in the outer circuit is now a uni-directional or a continuous current, so called in contradistinction to a to-and-fro or alternating current.

Perhaps a simpler conception of the continuous-current dynamo is formed by picturing whatever part of the revolving coil is uppermost to be delivering current to the upper brush, thence round the outer circuit or main back to the lower brush, which returns it to whatever part of the revolving coil happens to be in contact with it. This arrangement of brushes and contact pieces is called a commutator, as it commutes the to-and-fro current of the rotating armature into a direct current in the mains.

We are now in a position to steal some of the current from the mains in order to energise the dynamo's electro-magnet. This we may do by simply making the wire round the electro-magnet

part of the outer circuit, causing the whole of the current to pass round the magnet on its way to the mains. If preferred we may take a separate wire from the one brush round the electro-magnet and back to the other brush, thus making as it were a short loop line, so that only part of the generated current will branch off and energise the magnet. This latter method is termed a shunt-wound dynamo, only part of the current being "shunted," whereas the method of connecting the magnet's coil as part of the main circuit is called a series-wound machine. A common practice is to combine both these methods, one on the top of the other, and such a machine is termed a compound-wound dynamo, and has the effect of giving a constant electric pressure under varying loads.

The dynamo is now self-exciting, producing the necessary magnetic field by the current generated in its armature, but as no current can be generated until there is a magnetic field set up, it is natural to ask how we are to get the current started. It was at first considered necessary to employ a battery to excite the field magnet until the current was set up in the armature, but very soon it was found that this was not necessary, as there was always sufficient magnetism in the iron forming the core of the magnet to produce a very weak magnetic field. The armature coil, revolving in this weak field, had a small current produced in it, and sending this around the magnet a slightly stronger field was set up, in turn generating a stronger current in the moving armature, and so on until the electro-magnet is fully energised or "saturated," and the full amount

of current is passing through the coils of the electro-magnet.

It is interesting to note that some dynamos, driven by steam power, were constructed with permanent steel magnets, before it was found out that the machine could be made self-exciting. Until this latter discovery was made no really efficient dynamo could be constructed, as permanent steel magnets can only produce a very inferior magnetic field.

The self-exciting dynamo did not arrive all in a hurry. The first idea was to use another small dynamo, with permanent steel magnets, and thus generate current for the electro-magnet of the large dynamo; but having once set out on the right road it was not long before the self-exciting dynamo was an accomplished fact. This important stage was not reached till 1870, so that the practical dynamo has only been in existence for little more than a generation.

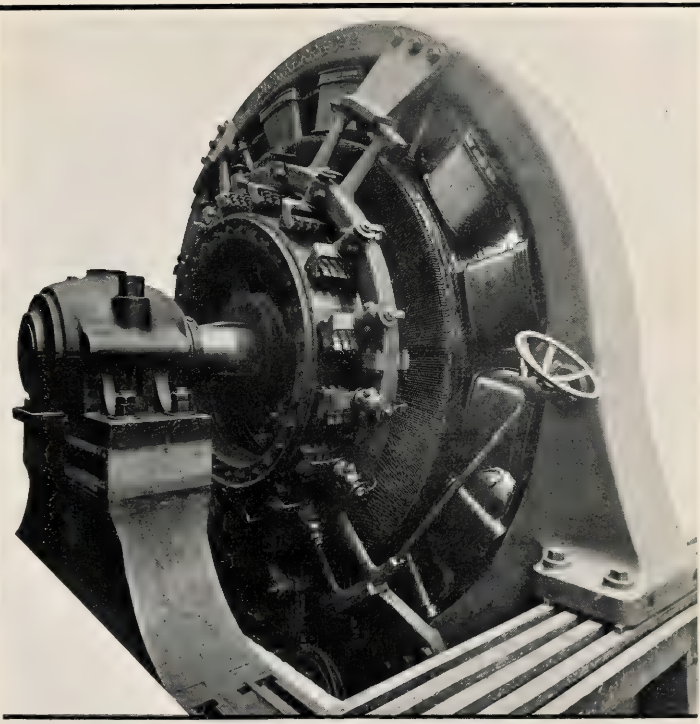
The dynamo which we have so far constructed, in imagination, would not be a very efficient machine, for, as the two contact pieces moved from one brush to the other, there would be a continual rise and fall in the strength of the current. To obviate this we may wind a large number of coils upon the armature shaft, and fasten the two ends of each coil to a pair of separate contact pieces, so placed around the shaft that when the one end of a coil touches the upper brush, the other end of the same coil simultaneously touches the lower brush. In this way we have a continual succession of contact pieces, so that as soon as one pair leaves the brushes another pair immediately touches them.

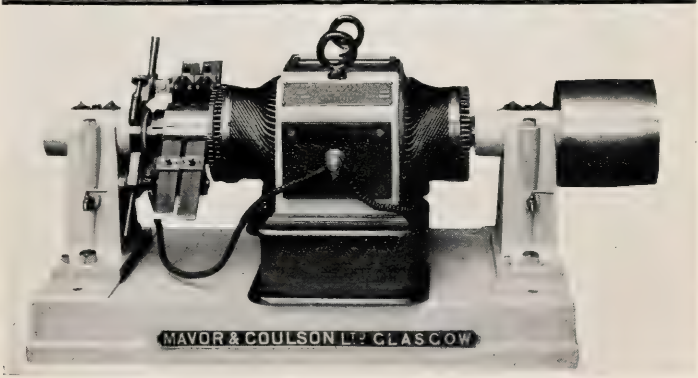
Instead of having a great number of separate coils

on the armature shaft, it is usual to have the coil wound in sections, a connection being taken at the junction of each section to a contact piece or section of the commutator. We may, therefore, picture the armature as one large coil, tapped at a great many places to keep feeding off the generated current continuously. However, if one finds it easier to think of the armature as a series of separate coils, each coming forward to the magnetic poles in succession, it does not matter, as the principle is the same.

It is advantageous to have as concentrated a magnetic field as possible, so there is very little space left between the periphery of the armature and the surrounding poles of the electro-magnet.

We may now sum up, in a few words, the principle of the dynamo. Its electro-magnet produces a powerful magnetic field, in which the armature is rapidly revolved, and from which the alternating current may be directly led away through the two complete rings placed alongside of each other, and the two brushes kept in constant contact; or we may, by means of a commutator, lead the current out as a continuous current into the outer circuit or mains. If we dispense with the commutator, and elect to take the alternating current straight to the mains, we cannot, of course, make the dynamo self-exciting, as we have no continuous current wherewith to energise the magnet. We must either fix a small continuous-current dynamo on the same shaft, to provide current for the large electro-magnet, or, if we have a number of alternating dynamos to drive, we may run one continuous-current dynamo to feed all the magnets.





1. A large dynamo showing a number of magnets producing the field, and several pairs of brushes collecting the current. The brushes are connected up into two sets, making, as it were, one pair of brushes. (Photo by permission of Dick, Kerr, & Co., Ltd.)

2. This small dynamo, although one of the maker's older types, has been selected because of its simplicity. It clearly shows the field magnet, the wiring of the armature, one double brush and part of the second double brush. The two double brushes make one pair. Both of the above generators, having commutators, supply direct current. (Photo by permission of Mavor & Coulson, Ltd.)

CHAPTER III

ELECTRIC TRACTION

Why a powerful engine is required to drive a dynamo—An amusing experience—The dynamo connected to the motor—Wherein the advantage lies—The electric tramway car—How the current is controlled—A puzzle in reversing the direction of the motor—How too great a current is prevented from reaching the motors—Protection from lightning—A most ingenious brake—Why we seldom see a disabled car

TO simplify the question of electric traction, I shall only deal with the continuous current dynamo for the present. We now see in the power station how the necessary current is generated, but why do we require such a powerful steam engine to revolve a simple armature, which can be made to spin round very easily on its well-fitting bearings? It is clear that it is certainly not the weight of the armature that requires such an immense power to turn it. It will be remembered that a coil of wire carrying an electric current is a magnet, and a large coil carrying a large current is a very powerful magnet, so that the armature of the dynamo becomes a strong magnet as soon as the current is set up in it. We have therefore to revolve one powerful electro-magnet (the armature) in the immediate neighbourhood of another powerful magnet (the field magnet); and it is to overcome the great attraction between these two electro-magnets that a powerful steam engine

is required. We have a very good illustration of this in connection with the ringing up of a subscriber on the telephone. After telling the exchange operator the number desired, one sometimes endeavours to ring up the subscriber before the necessary exchange connection has been made, and one feels the handle of the generator go round very easily, but just then it becomes stiff all at once, and there is now quite an appreciable load. At first there was no complete circuit, the wires not being connected at the exchange, and therefore when the armature of the little dynamo or generator was turned, there was no current generated in the armature; but when the operator connected the line wire to the other subscriber the circuit was completed, and the armature coil immediately became part of that complete circuit, so that a current was then generated in it at each movement, and it therefore required some appreciable energy to turn the crank.

An amusing experience in this connection has just been related to me by an electrical engineer who is abroad. In his power station they pump very large quantities of water, for the town's supply, &c., when the dynamos are not required in the daytime. I presume there had been some overlapping in the demand for water and for electricity, for one member of the council, who had been studying up some engineering books, said at a recent meeting of the council, that he did not see why the turbines (or engines) could not drive the dynamos and the pumps at the same time, for as far as the dynamos were concerned there was only a very small amount of friction between the brushes to overcome! I wonder

what the same councillor would think of our tramway stations using a four or five thousand horse-power engine to turn each armature. He would doubtless suggest a small gas engine.

Reverting to the continuous-current dynamo being energetically driven by the steam engine, we place another dynamo at a little distance apart, and then lead the current from the brushes of the generating dynamo to the brushes of the second machine. The current now passes round its electro-magnet and through its armature coils. The armature is at once attracted into a certain position; we may suppose the face of a coil which is a south pole being then attracted towards the north pole of the field magnet, but whenever it makes a half revolution it feeds from the opposite brush, so that its advancing face is now a north pole and it is attracted towards the south pole of the field magnet. At the end of its second half-revolution it has returned to its first position, and is therefore pulled forward by the other pole, and so on and on it will go, the current in the armature coil being continually reversed as the contact pieces touch first one brush and then the other.

The quicker we drive the generating dynamo the more current will reach this second machine, which is now a motor, and the quicker it will go. But we need not alter the speed of the generating dynamo in order to alter the speed of the motor, for we can switch off and on the current at will, and if we desire a smaller current to reach the motor we can put some resistance in the current's path. If we desire to draw water from a cistern giving a certain fixed pressure, we can regulate the rate of flow as desired by turning

a stop-cock, withdrawing a resistance we have put in the path of the water. Similarly, we place a number of coils of wire of definite resistances in the path of the electric current, and by moving a switch we can direct the current through any number of these resistances we desire, just as one may turn the stop-cock of a water-pipe so that it is three-quarters, half, quarter, or full open. If we switch out all the resistance coils from the circuit we let the full current from the dynamo get to the motor.

We can now couple the motor to any machine, or to a line of shafting from which a number of fixed machines can be driven, but what advantage are we going to have? We might as well drive from the engine direct, for it is clear that the dynamo and motor must have lost some of the initial energy of the steam engine. Fortunately this loss is very small indeed, the motor giving about 90 per cent. of the power of the engine. The great advantage, however, is that the motor may be far distant from the dynamo and its steam engine. We have therefore the transmission of power by electricity to very long distances, and without any movable connection between the places. A power station may be built in a busy centre, and stationary wires may be led out in all directions, enabling power to be distributed to factories, workshops, or private houses. The gigantic power of our great waterfalls can thus be carried to a distance and utilised. The only condition is, that there shall be a complete path for the current to pass from the dynamo to the motor. We have already seen that it is not necessary that there be one continuous fixed attachment; it is sufficient if

there is merely contact. The motor need not therefore be fixed in one stationary position, as long as we keep in touch with the electric circuit. In this way a motor may be mounted underneath a tramway car, and its armature shaft directly geared to the axle. The current may be led out from the dynamo in the distant power station, along an overhead wire stretched above the track, while a "trolley" pole on the car keeps in touch with the wire, and conducts the current to the motor under the car. After passing through the field coils and armature coil of the motor, the current proceeds by way of the wheels and the rails of the ordinary track, back to the other brush of the dynamo in the generating station. The current is under the complete control of the motor-man on the car, as it has to pass through his controller box on its way to the motor. This controller box is merely a means of switching the current from one connection to another, switching out or in any desired number of resistance coils, or breaking the circuit altogether. When the handle of the controller is turned into one position, the current's only path is through all the resistance coils, but moving the handle to the next notch cuts out one or two coils, the next notch a few more, and so on.

The resistance coils on a tramway car are usually made of long strips of german-silver, or of steel ribbon wound up in bobbin fashion, the one turn being insulated from the overlapping turn by placing sheet mica between them, so that we really have a metal ribbon which is the conductor, and a mica ribbon which makes a splendid insulator, and forces the current to go through the whole length of the

metal ribbon, just as water might be forced through a large spiral coil of pipe. The resistances are usually made up for convenience into two frames, each looking like a long cylinder, and these are placed out of the way underneath the platforms of the car. The current, after leaving these resistance boxes or "rheostats," goes direct to the motor. There are really two separate motors below a modern tramway car, one being geared to each axle. By means of the controller switch the motor-man may send the current through the two motors "in series," the current passing through the one motor and then the other. This he does when starting the car from a standstill, or when slow speed is necessary. When full power is required the motor-man turns his switch into a position which causes each motor to feed direct from the overhead wire. The motors are then said to be connected "in parallel." In addition to the main switch, there is a small lever on the top of the controller box, by means of which the direction of the current may be reversed, in order to drive the car in the opposite direction.

There is an interesting point in connection with a continuous-current motor. I have often been amused to find some youthful possessor of a small electromotor puzzled as to how he may reverse the direction of rotation in his motor. He reverses its connections with the battery, which is his source of power, thus causing the current to flow through his motor in the opposite direction; but the motor goes off in the same direction as at first, and reverse the current as often as he likes, the motor will insist on rotating in the one direction only. The explanation is very simple, for

when the current is reversed it flows through the armature coil in the opposite direction, and will therefore alter the magnetic faces of the moving coils, which should certainly make them rotate in the opposite direction, but the current is also going round the field magnet in the opposite direction, so that its poles are also reversed. We all know that "two negatives make a positive," or, in other words, if you face round into the opposite direction twice, you are just back to where you were at first. It is clear, therefore, that we must reverse the current in one part only, and it is more convenient merely to reverse the armature connections, thus changing the direction of its current and leaving the field magnet constant.

Before leaving the car, there are one or two other points of interest. It is necessary to protect the coils of wires in the motors from receiving too great a current, and possibly fusing or melting the wires, should any sudden increase of current occur in the mains. An automatic switch is placed in the current's path, on its way from the trolley pole to the controller box, and is usually fixed to the roof of one of the platforms. At the other end of the car is another switch in a similar position. This switch is of similar appearance, but is not an automatic one. The current first of all passes through this switch, where it can be cut off if desired, and then to the automatic switch at the other end of the car, and thence it passes to the controller box. The automatic switch may also be turned off and on at will, but it is so arranged that it will be thrown off by an excess of current. It is arranged so that the increased current energises a

solenoid or electro-magnet, and causes it to attract a lever which releases the switch, causing it to go over to the "off" position. The motor-man has simply to move the switch again to the "on" position, and no harm has been done, the excess of current having been prevented reaching the electrical equipment of the car. This automatic switch, being at one end of the car only, will at one time be over the head of the motor-man, and when the car is going in the opposite direction it will, of course, be over the head of the conductor. I have seen it so happen that a passenger was standing on the platform under the automatic switch when it "blew-out," and as there is a momentary arc formed by the current flashing across the switch connections, there is a considerable and sudden noise, such as accompanies a gun-shot, which is rather alarming to the uninitiated, although there is no danger whatever.

Then the car equipment must be protected against a possible discharge of lightning striking the overhead wire, and reaching the motors. Lightning is a sudden discharge of electricity at a very high pressure, and therefore is of a different nature from the overload of current, so that the automatic switch just mentioned would not be operated by lightning. A very simple device suffices to lead away the lightning discharge to earth. There are many forms of lightning arresters, but the essential point in all is to provide a short cut for the lightning, and yet make this path impossible for the ordinary current. If we made a direct earth connection from the car circuit, the current from the generating station would all take this easiest road and never reach the motors; but if we ima-

gine such a short cut made, and we then remove a very small piece of the wire forming the earth connection, it will be impossible for the ordinary current to get over the small air gap made, so that the current must pass on to the motors and do its work. Lightning, however, can laugh at such small difficulties as tiny air gaps, it is at such an immense pressure that it easily jumps across them, and gets to earth without troubling to go round the motor coils, which is very convenient for our purpose. The simple air gap, as just described, is quite sufficient in itself to protect a circuit where the ordinary current is small, such as is the case with telegraphs and telephones, but when the ordinary current is a powerful one, such as is required to drive the cars, we have to take a further precaution. The ordinary current for the car cannot jump the air gap under normal conditions, but if a lightning flash first jumps the space and sets up a momentary flash or arc, which carries with it very tiny particles of the metal, it can then do so. This metal vapour forms a drawbridge, as it were, by which the ordinary current can cross. It is therefore necessary that the lightning arrester, to be used in connection with powerful currents, must automatically break the circuit as soon as the lightning flash has crossed. This may be very simply done by having one of the air-gap points a movable one, and under the control of an electro-magnet, so that the first rush of current energises the magnet, and the movable piece is at once withdrawn, thus increasing the length of the air gap, prohibiting the current jumping across. Lightning arresters are also placed on a certain number of the poles supporting the overhead wire along the streets, and

others again at the generating station, so that the whole equipment is well guarded against any possible damage by lightning.

To sum up the electrical arrangements on the car, we may picture the current passing from the distant station to the overhead wire, and thence by a wire in the trolley pole to the automatic switch, the controller box, the resistances, the motors, thence to the rails, and back to the generating station.

The electric current for the lighting of the car branches off from the main circuit of the car, passing through its own switches, its circuit being quite distinct from the power circuit, and having no connection with the controller box, &c.

There is one other point in connection with the car itself, which I think of special interest, and that is a very ingenious method of providing an efficient brake. The motor-man has, of course, the ordinary hand brake, but as his car possibly weighs nine or ten tons, and as he may have occasion either to pull up very suddenly, or to use a heavy braking power on a steep hill, he is provided with a second brake. One of the best forms of this additional brake is an electro-magnetic arrangement, in which a metal "slipper" is placed close to the rail; this may be seen in the accompanying photograph of a car (page 56). The slipper is practically the pole of an electro-magnet, and when it is magnetised it is attracted down to the rail; it will, of course, tend to fall behind the car, and is allowed to move slightly backwards, so that it moves some levers, and causes "shoes" to be pressed against the car wheels. The interesting point of the arrangement is, that this electro-magnetic brake is not de-

pendent upon the overhead current to energise it. It would be of little use if it were thus dependent, for, to take only one instance, the trolley pole might have left the overhead wire while the car was gathering speed in going down a very steep hill, and then the brake would be powerless, as no current could reach it to energise its magnets. It is therefore arranged that there is no connection whatever between the trolley current and the electric brake.

If we picture a car racing down a hill, with the controller switch "off," so that no current can get to the motors, the armatures of the motors will, of course, be still flying round, because they are geared to the axles, and must therefore turn with the axles of the car. We have an armature spinning round between the poles of an electro-magnet, which arrangement is in point of fact a dynamo, its magnet being fed from the rotating armature. Here we have an available current for the brakes, the motor for the time acting as a dynamo. It is just as good as though the car was specially carrying a generating dynamo for the purpose, and as the source of power is the moving car, it is exactly the kind of arrangement we desire. If the car has gathered great speed, then the "dynamo" is running very fast, and we get a powerful current to operate the brake; whereas, if the car is only going slowly, we get a weaker current, which is all that is required to pull up the car in this case. Not only do we have the mechanical friction which is produced to help us in pulling up the car, but we have in addition quite another force coming to our aid, for the "dynamo" itself becomes a retarding force. We require a powerful engine to drive a

dynamo armature round, because of the great magnetic attraction between the armature and the field magnet; we may picture the dynamo and engine fighting with each other, as it were, the dynamo pulling against the force of the engine, and trying to stop it. In the present case the only source of power is the moving car, so that the "dynamo" will be pulling against this power, and trying to stop it. Perhaps a simpler way of looking at the matter is to picture the dynamo as being composed of one magnet spinning round close to another stationary magnet, the latter trying to stop the revolving one, so that we must keep supplying the engine with fresh steam in order that it may overcome this attraction. In the present case the source of power is not a fixed propelling force such as an engine, but is merely the impetus provided by the moving car, so that the stationary magnet does succeed in stopping the revolving magnet; and as the wheel-axles are directly geared to the "dynamo," the car is pulled up.

We might say that, in the arrangement just described, we have an ideal brake, and indeed the only fault that can be found is that it depends upon the electrical equipment of the car being in good order. That is to say, if the motors had broken down at the time the brake was required, there would be no current available for the brake. However, this contingency is a very improbable one, for the faults occurring in the motors or in the wiring are remarkably few. Glasgow has been practically free from such faults, and this no doubt is due to a very excellent plan adopted whereby every car is periodically examined.

It is arranged that every car must be overhauled at

the end of each six weeks, being sent to the repairing works to have all its working parts very carefully examined and tested. After a car has completed a year's runs, it is sent to the repairing works to have the whole working parts, including the springs, &c., practically taken to pieces and rebuilt. I fear that many people, even in well-managed tramway centres, may think that there are very frequent breakdowns in the going parts of the cars, for one is constantly seeing one car, with its trolley pole fastened down, and apparently in a helpless condition, being towed along by another empty car, marked "Depot only." This is really not a disabled car being taken in hand by a more fortunate mate ; these are merely two cars being sent from one district depot to the repairing station for their six-weekly or annual overhaul.

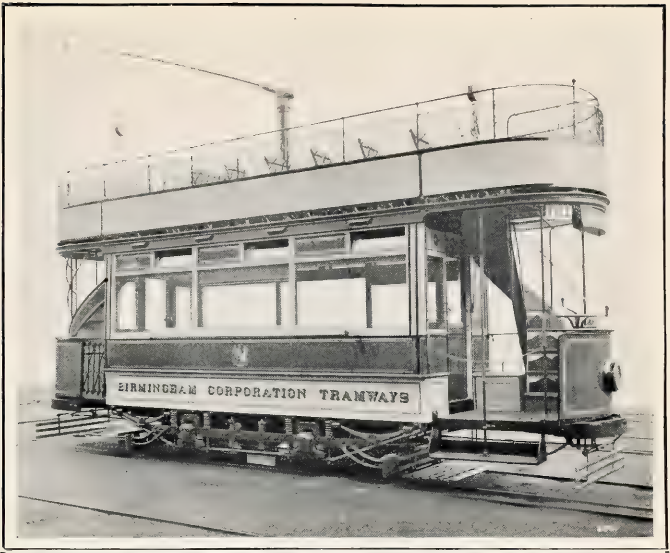
CHAPTER IV

A LARGE TRAMWAY UNDERTAKING

The power station—The sub-stations—A dangerous current converted to a working pressure—How a to-and-fro current is changed to a continuous current—How the pressure of a continuous current is altered—The return circuit—Is the overhead system dangerous?

As so many cities and towns are now possessors of electric tramways, it may be of interest to know the method of working a large undertaking. To take the city of Glasgow, by way of illustration, we find that current must be supplied to cars running in every direction throughout the city, and far beyond the outskirts, as far as ten miles from the centre of the city. It is advantageous, as will be seen later, to have one large power-station, so that all the furnaces, boilers, engines, and dynamos are in one place. The electric current is not to be sent direct from this station to the cars, but to a number of sub-stations conveniently placed in the different districts, there being five such sub-stations or distributing centres in Glasgow.

It is found more economical to send the current to these distant stations under a high electric pressure, for reasons which will be better understood later. We speak of the pressure of an electric current being so many hundred, or so many thousand, volts, the volt being the unit of pressure. For the

I 

2 

1. A modern tramway car. The trolley-pole conducts the electric current from an overhead wire to the electric motors placed below the car. A small block is seen close to the rails between the wheels. This is part of an electro-magnetic brake.

2. Tramway cars in use. (No. 1 is by permission of Dick, Kerr & Co., Ltd.)

present I shall only mention voltages for the sake of comparison, leaving the value of the volt to be explained in a later chapter on electrical measurements.

In the power station at Glasgow, the dynamos generate the current at the immense pressure of 6500 volts, and for any one to get into the circuit of this current means certain death. It is not intended, however, to send this voltage to the tramway cars. Cables are buried deep in the ground, and carry this current from the dynamos to the different sub-stations. The generating dynamos, of which in this station there are four, are very large, each requiring a powerful engine of from 4000 to 5000 horse-power to drive it.

The current is led away from the power station as an alternating current, and reaches the sub-station at the high pressure already mentioned. Having reached the sub-station, it is necessary to bring this immense pressure down to a working voltage, and this is accomplished in a very simple way. On reaching the sub-station the current is made to flow through a large stationary coil of wire, and then back to the generating station. It has therefore a complete circuit from the distant dynamo, through the underground cable, then up to the surface in the sub-station, through this stationary coil, and away back by the return underground cable to the dynamo. This certainly seems a very strange proceeding, to take the current into the distant sub-station, and apparently send it back again without making it do any work. But it really has done some work, for we know that when an electric

current flows along a wire it sets up a magnetic field around the wire. With a single wire this effect is not very great, but if we coil up the wire we get a very considerable effect, so that this current from the generating station, in passing through the large coil in the sub-station, has set up a very powerful magnetic field in its immediate neighbourhood. We know that if we move a simple coil of wire in a magnetic field there is a current of electricity generated in the moving coil. Our object in moving the coil is to get it to cut the magnetic lines of force, but it is evident that the same result may be obtained by moving the magnetic field, so that the lines of force pass through a stationary coil. It so happens that the powerful magnetic field which has been produced in the sub-station is not a steady magnetic field, for it is produced by an alternating current, which is continually swinging to and fro very rapidly, so that we practically have a moving magnetic field, although the magnetising coil is stationary. We only require to place a second stationary coil of wire in this changing magnetic field, and we find a powerful current is induced in this second coil. That is to say, we have an alternating current swinging to and fro in one coil, connected to the distant generating station, inducing a similar current to be set up in an adjacent coil.

At first sight there seems to be no advantage whatever in the simple arrangement of two coils just described. What have we gained? We can certainly have no more energy in the second coil than in the first; indeed it is quite apparent,

from the heat developed in and around the coils, that some energy has been dissipated. There is, of course, some advantage gained, or this inducing of a current in a second coil would not be found in the sub-station. The advantage is that in transferring the energy, as it were, from the one coil to the other we can alter the pressure of the current to any degree we desire. All that we have to do is to make fewer turns of wire in the receiving coil than there are in the generating coil, and we find that we have reduced the pressure of the current. If, on the other hand, we were to make a larger number of turns in the receiving coil, we should find that the pressure of the induced current had been increased. In the present case we desire to reduce the dangerous voltage of 6500 volts, to a working pressure of a few hundred volts. The relationship of the two coils is made so that the high-pressure current is "stepped down" to 330 volts. Be it understood, we have merely reduced the pressure of the current, and correspondingly increased its rate of flow; we still have practically the same activity.

The arrangement of coils, as just described, is called a transformer, as it transforms the current from one voltage to another. If we had a current of water flowing through a small pipe at a very high pressure, and we greatly reduced the pressure, we should then require to use a larger pipe to carry the water, if we intended to get it through in the same time. Similarly with the transformer; we have a high-pressure current in the first or "primary" coil, and in order to have a large number of turns conveniently arranged in this coil, we use the smallest

wire that will safely carry the current, but in order to carry the greater rate of flow at the lower pressure we require to use a much larger wire in the second or "secondary" coil, and this we can quite conveniently arrange, as we are not having nearly so many turns in the coil.

This low-pressure current of 330 volts, which we now have in the secondary coil, is, of course, an alternating current just as in the coil that induced it, but it is desired to convert this to-and-fro current into a direct or continuous current before sending it out to the cars. How is this to be done? Simply by making the current drive an alternating motor, and then causing the motor to drive a continuous-current dynamo. In the construction of the latter, we may arrange that the continuous current will be generated at any desired pressure. If we picture a motor driving a dynamo, we see that there are two similar armatures spinning round in two separate but similar magnetic fields. Why not make the one magnetic field do for both, and place the two armature coils together on the one shaft or spindle? As a matter of fact the one armature coil will do, as we can lead in the alternating current by means of brushes and complete rings, as previously described, and we then may tap the coil at the other end, and lead current out through the brushes of a commutator, which will then be a continuous or direct current. I can imagine a stranger entering a sub-station, and not knowing of this arrangement, being very much puzzled to see this large motor going full speed ahead, and yet apparently being called upon to do no work. It is, of course, doing energetic work, for

while its armature is being made to spin round by the current received from the transformer, previously described, this same motor's armature is also acting as a dynamo's armature, which it is forcing through the magnetic field, against its will as it were.

It may be that some reader wonders wherein lies the difference of this armature from that in an ordinary or single motor. The difference is that in the motor the current enters the armature by one brush, and has a closed path through the coil back to the other brush, whereas in the machine just described, the coil is tapped and some current is being led away through a commutator, so that the armature will call for more current to keep it spinning round as a motor. A machine of this kind is called a rotary converter, or sometimes merely a rotary, and its function is to convert an alternating current into a direct current. We may reverse the order of things by supplying the machine with direct current at the commutator side, and drawing off alternating current from the rings at the other side.

There is another point which I shall merely mention here, as it does not necessarily refer to the sub-station work. It is sometimes desired to alter the pressure of a continuous current, say from 500 volts to 200 volts. It will be clear that we cannot do this by a simple arrangement of two coils as used in the transformer for an alternating current, for the continuous current being in one direction all the time, will set up a steady magnetic field in the first or primary coil, which could only affect the secondary coil at the moment of setting up and

withdrawing the magnetic field, by turning on and off the current. We have no natural changing field, and to attempt to make and break the circuit to produce a changing or moving field is not convenient for the present purpose, although we shall find this of use for other purposes, when we come to consider induction coils in a later chapter. The best we can therefore do, is to make the 500-volt current drive a continuous-current motor, and cause this motor to drive a continuous-current dynamo, the latter being constructed to give current at 200-volt pressure. The one machine might drive the other by a belt, but it is better still to place the two machines alongside of each other, and let one long shaft or spindle run through both machines, the armature coils being placed in their respective magnetic fields. In this case we really have two machines, but it is possible to use one magnetic field only, and to mount the two separate armature coils on to one shaft, still keeping the two circuits quite distinct, and then the coils will rotate in the one magnetic field. A machine so constructed is called a motor generator, and its function is merely to alter the pressure of a continuous current, either raising or lowering it as desired, each machine being specially wound to give any one desired effect.

To return to the subject of our tramway cars, we had, by means of the rotary converter, changed the alternating current of the transformer into a continuous current, suitable for leading out to the overhead trolley wire. In the Glasgow undertaking it is arranged that this current is at a pressure of 500 volts.

As the description of these intermediate operations has been somewhat lengthy, I shall briefly sum up the points directly bearing upon the production of this final current. The distant dynamos at the generating station send out a highly dangerous current at 6500-volt pressure to the sub-station, where it is stepped down by the stationary or static transformer to 330 volts. This alternating current then drives the rotary converter, which delivers a continuous current at 500 volts, which is the current required to drive the motors on the moving cars.

When this current has to be sent to any distance, we do not depend upon the overhead trolley wire to carry the current for the whole route. It is therefore convenient to divide the trolley wire off into sections of rather less than half a mile in length, and then to feed the current on to each of these sections from underground cables or feeders. One sees the connecting wires from these feeders passing up to the trolley wire every here and there along a tramway route. Such places may easily be distinguished, as there is a large cast-iron switch-box, in appearance something like a dust-bin or letter-box, standing on the pavement at these points. The underground feeders come up into this box, and then a wire passes from the box up inside one of the poles to the overhead trolley wire. It may here be mentioned that a guard wire is suspended at a little distance above the trolley wire, so that if a telephone or telegraph wire, passing overhead, break and fall down, it will be kept clear of the "live" wire.

The return circuit to the sub-station is, as already indicated, by the rails, and it is therefore necessary either to weld the rails into one continuous length, or to bind them together by copper bonds, or otherwise connect them so that the current may easily pass along from one rail to the other. It is usual now, and indeed I think it is compulsory by the regulations of the Board of Trade, to feed off the current from the track at intervals to underground cables, and thence to the sub-station. At first it was thought sufficient to do without this, but it was soon found that the current affected neighbouring water and gas pipes, setting up chemical action resulting in time in deterioration or decomposition of the metal pipes. So much was this the case that the water and gas companies insisted on a complete return circuit being provided for the current.

We have now formed a fairly comprehensive view of a large tramway undertaking, on the overhead trolley system, though a great deal of detail, that might not be of general interest, has purposely been omitted.

Some cities object to the overhead wire system, either from an æsthetic point of view or from fear of accident, but one very quickly becomes accustomed to the sight of the overhead wires, so that one almost ceases to notice them ; and as regards danger, there is really very little risk of any serious hurt being done. Indeed, even if the overhead wires were at a highly dangerous voltage, at which they are not, there would not be any great risk, for the condition of the overhead conductors is so well looked after that they practically never

get a chance of coming down. The city of Glasgow has had an overhead system at work since 1901, having now about eight hundred cars in operation, and there has not been a single fatal accident in connection with the overhead conductors.

In the illustration placed opposite page 86, there is shown a novelty in electrically-driven vehicles. This fire-escape carries its own generating station on board itself. A small petrol engine drives a dynamo, which passes on the power to two electric motors fixed on the axle of the front wheels. It is a great advantage to be able to drive the front wheels on such a heavy car requiring to travel at a high speed. The front wheels, being the steering ones, could not be driven directly by a petrol engine. This 85-foot ladder, which is in use in Glasgow, is automatically extended by compressed carbonic acid gas.

CHAPTER V

MORE ABOUT TRAMWAYS, RAILWAYS, &c.

Some remarks about fatal shocks—Wherein the chief danger lies—Keeping the live rail out of the way—The conduit system—The surface-contact system—The electrification of railways—Electric motor cars—Electric launches—Electric tools—A look ahead.

How is one to know whether an electric shock is likely to prove fatal or not? In considering the case of a fallen trolley wire carrying current at a pressure of 500 volts, the severity of the shock will depend altogether upon the resistance offered to the passage of the current from the wire through the body to earth. The resistance of the body alone will not prevent the current getting through, but if the person is standing on the paved street, and especially if the stones be dry, there is a very considerable resistance placed in the current's path, and the shock will not be fatal, if it is even severe. Sometimes when an overhead wire has fallen down upon the paved street, the wire has remained "alive," for the path offered the current does not enable sufficient to rush to earth to operate the safety devices. If the wire falls on wet ground adjacent to the rails, or upon the rails themselves, an automatic switch of much the same design as that previously described, as installed on cars, comes into operation and causes the power to be cut off from the disabled line. A fallen line

By permission of *Siemens Schuckertwerke, Berlin*

THE FIRST PUBLIC ELECTRIC RAILWAY

This miniature passenger train was a great novelty at the Berlin Exhibition of 1879.

should never be handled with the bare hands until one is assured that the line is dead. If it is necessary to handle the line, and rubber gloves are not available, it should be grasped with a folded newspaper, a cap or tobacco pouch covering the hand. With these precautions a live wire can immediately be rendered dead by lifting it into contact with the rails.

When in a provincial town recently, I saw the trolley pole of a car spring off from the overhead wire and break one of the stays of the guard wire, and this stay wire, falling upon the "live" trolley wire, produced a rather alarming display of lightning flashes, as it swung to and fro. It fortunately came to rest free of the trolley wire, but seeing the motormen and conductors puzzled as to how they should act, I got into conversation with them. One man had donned his large rubber gloves, which is in every case a wise precaution, but finding that he had difficulty in bracing himself up to go forward and touch the disabled wire which had so recently dealt out alarming flashes, I assured him that as long as he kept it free of the trolley wire—and there was no difficulty in doing so—the wire was perfectly harmless. With this knowledge he handled the wire without fear, and got it securely tied up out of danger. In all cases of a breakdown it is only wise to consider carefully the effect of any proposed action, and it is clear that the one thing above all others to avoid is any possibility of getting in contact with the rail while handling the disabled wire. There is no danger in standing upon the rails when the trolley wire is secure overhead, nor would there be any danger of shock whatever in sitting upon the trolley wire while

suspended in the air, only one would need to keep clear of the guard wire, as it is "earthed." But to get in contact with both the trolley wire and one of the rails simultaneously, is to make the body a part of the direct circuit; and any unfortunate person so situated, receiving the full load of current, will certainly receive a very serious shock, which in some circumstances might prove fatal. On the other hand, if the paved street be dry, and the motor-man, armed with his rubber gloves, lifts the disabled wire, he may safely place it on the rail, for the current will immediately flash direct by the rail, not troubling to pass through the resistance he and the paved street offer to it. If the streets are wet, or from any other cause offer little resistance, then there is considerable danger in handling the disabled wire without proper insulating gloves. Indeed, the only wise plan in such a case would be to leave the disabled wire alone until the current could be switched off. There is an invention whereby the current is locally switched off when a trolley wire falls, but I have not happened to see it in use; possibly the risk of overhead wires coming down is so small that this precaution is not considered a necessity.

Some cities will not have the overhead wire method, and adopt in preference the conduit system, in which the "live" wire is carried along the centre of the track in an underground channel. The car is provided with a current collector or "plough," which passes down through a slot and makes contact with the live wire underground, the rails being used as the return circuit, if it is so desired. The appearance of a track on this conduit system is identical with that of

a cable haulage, or endless rope, system. The conduit system is much more expensive to instal than is the overhead system, and there is considerable expense in upkeep, and in cleaning the conduit.

There is another principle of traction known as the "surface-contact system," in which the live rail is securely buried out of reach immediately below a surface rail, but not in contact with it. This surface rail is a third rail, and has no connection with the two rails of the track. There is no danger whatever in standing in contact with this surface rail and the return rails of the track simultaneously, as the surface rail is not in the circuit. How is the car to get in contact with the live rail which is out of reach? There is no contact between the live rail and the surface rail, but only a small space separates them. Imagine, by way of illustration, a long iron chain lying on the top of the underground live rail, this chain being in the space just spoken of, but still quite free of the surface rail immediately above it. If a powerful electro-magnet is placed upon the top of the surface rail the chain will be attracted upwards against the underside of the surface rail, and in this position the chain will form a bridge between the live rail and the surface rail. If the car carries the electro-magnet along with it the chain will always rise immediately under the magnet, so that the part of the surface rail immediately under the car will always be in contact with the live rail. The car is therefore indirectly in contact with the live rail, and thus receives the current from the distant station, and the current, after passing through the motors on the car, returns by the rails of the

track to the station. As the car moves along the chain falls down, being no longer supported by the magnet on the car. One may picture the chain being given a sinuous or wave-like motion, a single crest travelling along with the car.

Surface-contact systems have been arranged on a somewhat similar method to the foregoing simple illustration, some form of sliding or rolling contact being placed in the space between the live rail and the surface rail, so that a bridge is formed. This sliding bridge travels along with the car under the influence of an electro-magnet carried on the car. Another plan is to have automatic switches, which make "studs" in the centre of the track alive as the car passes over them. The cars carry a skate underneath, which makes contact with the live studs. Only short lines have been thus equipped.

Having gone so fully into the subject of electric tramways, it would not be of general interest to go into somewhat similar particulars in connection with electric railway trains, so I shall merely make one or two general remarks.

A train may be drawn by an electric locomotive on which powerful motors are placed, or the passenger cars themselves may carry the motors underneath their frames in the same manner as electric tramway cars do. The current may be collected from an overhead wire or from a third rail, placed either between the track rails or alongside the track. This third rail is, of course, the live rail, while the track may be used as the return circuit, as in the case of tramway cars already dealt with. Some arrange-

ments of power transmission require two or even three overhead wires, but I do not think it necessary to go into further particulars here.

The progress of the electrification of railways must necessarily be slow, because of the large capital locked up in existing plant and rolling-stock. We have already seen many suburban lines electrified, and the Metropolitan District Railway (London), the old Underground, has received new life by the change to electricity, and is so far one of the largest undertakings of the kind. While we cannot hope to see any of the long-distance railways electrified in the immediate future, we shall doubtless see an increased conversion of suburban lines, and there seems little doubt that ultimately the longer lines will follow. With the practical experience gained in the operation of these shorter lines the engineers will be better able to provide for the larger orders.

Electricity would be the ideal motive power for private motor cars but for the difficulty of obtaining the electric current. The electric carriage, or electromobile, cannot keep in touch with a fixed live wire, and so it is necessary for the source of power to be carried about by the car. This means a deadweight of heavy accumulators, from forty to fifty cells, weighing in all about half a ton. These storage cells or accumulators may be carried in a large box at the rear of the vehicle, or may be divided into two boxes, one placed in front and the other behind. An accumulator is like a clock wound up to go for a certain time, only the clock is expected to do its work at an even rate continuously, whereas

an accumulator's energy is tapped as required. When exhausted the accumulator has to be re-charged with the current from a dynamo, just as the clock requires to be re-wound. The distance that an electromobile can go with a full charge is from thirty to forty miles, at the end of which distance it must be taken to a generating station, where its exhausted accumulators may be exchanged for a fresh set, to save a long wait on the re-charging of the discharged ones. The subject of accumulators will be dealt with in a later chapter.

The necessity for continually re-charging the accumulators prevents the electric carriage from going to any great distance from a generating station. One might travel by electromobile from Land's End to John o' Groats, if one was sure to pass an electric power station every thirty miles, where the discharged accumulators might be exchanged for charged ones.

The electromobile makes an ideal private carriage for use in large cities, where companies cater for the supply of charged accumulators. In London there are very many already in use, while one notices the advent of the electric motor car in other large cities. The advantages are that the car is so easily controlled, being operated by a single switch, after the manner of a tramway car. Then the electric motor car starts off so quietly, and is free from the rapid vibration and the smell, which faults are still associated with the petrol car. The method of altering the speed in an electromobile is on a different system from that described in connection with the tramway cars. In the latter we

merely place or withdraw certain resistances in the current's path, thus varying the current's strength, but in the case of the electric carriage, we merely alter the arrangement of the connections between the battery and the motor's field magnets, &c. It is usual to have two motors, one geared to each of the back wheels, though sometimes the car is arranged with the motors on the front wheels. To sum up, we may imagine the electromobile being fed every thirty to forty miles, and after it has made runs totalling from 1500 to 2000 miles requiring to have some of its battery plates renewed.

Electricity has been applied as a motive power for boats, and in this connection it is interesting to note that electric launches actually existed before the invention of the dynamo or the accumulator. Of course these boats were not very efficient craft, having to depend on current from a primary battery, which gives a very intermittent supply. The principle of the motors was necessarily very primitive, being a sort of see-saw arrangement actuated by electro-magnets. These early experimental boats, which could carry a dozen people, attained a speed of from one and a half to two and a half miles per hour. A modern electric launch, such as one sees on the Thames, may attain a speed of six to eight miles per hour, but is tied, in the same way as an electromobile is, to the neighbourhood of generating stations. The total run available on a single charge is very similar to that of the electromobile, varying from thirty to forty miles. On the Thames, where a large number of electric launches ply for hire,

there are twenty generating stations between Oxford and Kingston, a distance of one hundred miles. The electric motor, of course, turns the propeller shaft, the speed of which may be regulated at will by a switch. The smooth gliding motion of an electric launch is very pleasing, while the absence of heat, smell, and dirt very materially add to one's comfort.

It would, of course, be possible, on a river, to run an electric boat fitted with a trolley pole to make contact with an overhead wire, after the manner of a tramway car, but this is not very convenient. Some canals have been fitted up in this manner, but it has been found that it is better to pull the boats by an electric locomotive or tractor on the tow-path.

Submarines have been built so that they could be driven by electricity while under water, and by steam or gasoline engines when on the surface. A boat thus equipped is capable of generating its own current while on the surface, and thereby charging its accumulators for submarine use.

It is on land that the electric motor has its wide field of action. Small motors may be fitted on to machine tools, and power may be conveyed from a distant dynamo to a tool held in the engineer's hand, as is shown in the accompanying photograph (page 182). It is most convenient to be able to carry power to any part of a ship, or a large bridge, under construction or repair.

Again, in connection with mining, electricity has proved of great service, enabling machinery deep

By permission of *The Engineering Magazine*

A Test Race

A series of speed tests were made between the latest electric and steam locomotives on the New York Central Railway.

down in the bowels of the earth to receive power from the surface. Electric coal cutters can therefore move about in the mine, merely keeping in contact with the distant dynamos on the surface.

In the future we shall doubtless see the erection of gigantic power stations, distributing electricity in every direction. It is only by such means that we can hope to reduce the cost of electric current to a price at which it will be able to compete with all comers.

Already the Niagara Falls power stations supply energy to motors distant between seventy and eighty miles from the source of power. Should our coal supplies become exhausted after a lapse of centuries, we should doubtless before that time have succeeded in economically transmitting power to far greater distances than it is at present possible to cover, so that our natural resources, such as waterfalls, tidal motion, &c., will supply us with ample power, heat, and light. How convenient to be able, as we now are, to transmit power by means of a stationary wire or cable, instead of by the clumsy method of carrying heavy coal about from one place to another, and then generating energy on a small scale for one's own use.

The illustration opposite page 74 is a photograph taken during some interesting tests made on the New York Central Railway. It was found that the electric locomotive attained full speed very much quicker than the best steam locomotive could do. During other tests in Germany it was found possible to run electric locomotives at a speed of 130 miles per hour.

CHAPTER VI

ELECTRICITY AS AN ILLUMINANT

The electric spark—Birth of the electric arc in London—The arc lamp—How the lamp works—An ingenious lamp controlled entirely by a hot wire—The enclosed arc lamp—The flame arc—Search-lights at the siege of Paris—Another valuable suggestion by Sir Humphry Davy—Early glow lamps—Amusing reminiscences of the early days—Why the carbon filament does not burn—A great boon—How the filament is made—How the lamp is made—A dangerous process—Some most ingenious operations—Recent inventions—A "Chamber of Horror" effect—When electric light may be universal

But for the advent of the dynamo, described in a preceding chapter, we would never have had electric lighting on a commercial scale, for although it was previously known that an intense light could be produced by electricity, there existed then no means of obtaining a steady and powerful current.

The experimenters who had worked with electrical machines had observed the somewhat feeble light produced by the electric spark, and even those who had handled batteries were aware that if a few cells were coupled together, and connected by two wires, a spark was always produced at the moment of disconnecting the wires. If the ends of the wires leading from the battery were merely touched together, a spark was invariably produced when the contact was broken.

Early in the nineteenth century there was a very large battery in use at the Royal Institution in London. It was, of course, a primary battery, as secondary batteries or accumulators did not come into use till after the birth of the dynamo; they would have served no useful purpose earlier. This great voltaic battery consisted of two thousand cells, and was used by Sir Humphry Davy, and by his assistant and successor, Michael Faraday.

Sir Humphry Davy found, on connecting the whole of this great battery to two wires, that when the wires were separated to a short distance, just sufficient to break the circuit, not only did a very brilliant spark appear, but a continuous sort of flame was produced. This flame was so very hot that the ends of the wires at once melted, so Davy fastened pieces of charcoal to the two wires, and upon bringing these together and then slightly separating them, he was able to show a very dazzling light to a large audience.

In these early experiments Davy placed the charcoal points in a horizontal line, and the heated air caused the flame to curve or arch upwards as it passed between the charcoal points. It so happened that some one called it an arc of light, which name has persisted to this day, although when the carbons are placed in a vertical or upright position, as is now the case, there is no appearance of an arc.

It was soon found that when the current leapt over from the one charcoal point to the other, it carried with it very minute particles of charcoal, and indeed there was formed a bridge of charcoal vapour. If the two charcoal points were brought very close together, but not allowed to touch each other, there

was no arc formed, as the current could not bridge even this very small air space. As soon as the charcoal points were touched together their points became red-hot, owing to the resistance they offered to the passage of the electric current, and if these red-hot points were then very slightly separated, the intervening space became filled with charcoal vapour, and the current could then cross by means of this gaseous bridge. The resistance offered to the passage of the current was so great, however, that the charcoal points were raised to an immense temperature, thus producing the powerful white light which we now recognise in the arc lamp, as used in our streets, railway stations, &c.

Davy used, in his experiments, sticks or pencils of wood charcoal, which burned away very quickly at so high a temperature, but other experimenters substituted a hard gas-coke, or coke-carbon, which was found to be of great advantage. We now make carbon pencils from a paste of finely powdered carbon, moulded under hydraulic pressure, and then further treated and subjected to a white heat.

It will be apparent that a lamp for producing a continuous and steady electric arc cannot be merely two clamps in which to fix the carbon pencils. In the first place no arc could be produced unless the points were made to touch and then separate, which action is described as "striking the arc." Then again, as the carbons waste away the one about twice as rapidly as the other, there must be some mechanism arranged to feed the carbons forward, and keep them at a constant distance, roughly about one-eighth of an inch. It has recently been found possible to

lengthen the arc to a distance exceeding half-an-inch, by altering the composition of the carbons.

In the early arc lamps the necessary operations were chiefly controlled by clockwork, but in modern lamps the mechanism is operated by electro-magnets. If a coil of wire be made up in a long cylindrical form, usually called a solenoid, a piece of iron will be attracted into this coil whenever a current of electricity passes through the coil, the solenoid itself becoming a magnet. This pulling force is in proportion to the strength of the current passing in the coil, and if the iron core be arranged so that it can slide up and down, it will rise and fall according to the increase or decrease of current in the solenoid. The iron core is just like a piston or plunger, and the solenoid like a cylinder. It is clear that if we fasten one of the carbon pencils to the plunger, it will be raised and lowered as the current in the solenoid rises or falls. Now if the carbons are left touching each other, and the current after passing through them goes through the solenoid, the current will easily get across from the one carbon pencil to the other as their points are in contact, but as soon as this current energises the solenoid, its plunger will rise and withdraw the one carbon pencil from the other, thus "striking the arc." If the current is switched off, the solenoid ceases to attract its plunger, and the carbon falls down again, but the moment the current is once more turned on, the arc is again struck. This action of the solenoid will also tend to regulate the distance between the carbons, for should the carbons come too near together, the current will more easily get across from the one

point to the other, and there will therefore be more current passing through the solenoid, thus raising the plunger and withdrawing the carbon. On the other hand, if the carbons are too far apart the current will have a greater resistance to overcome, and will therefore be reduced in the solenoid, allowing the plunger to fall and bring the one carbon nearer to the other. This very crude description will show the general principles upon which arc lamps are operated. In practice it is usual to have both of the carbons controlled by plungers and solenoids. These solenoids have often a double winding, one coil "in series" or in the main line of the current, and the other in a "shunt" or loop line. The solenoids and plungers may be caused to operate a see-saw lever and brake arrangement, but further detail will not be of much interest to the general reader. The points of interest are that the switching on of the current causes the lamp to automatically strike the arc, and the current passing through the solenoids also controls the distance of the carbons from one another, maintaining a steady arc. If an arc lamp makes a hissing noise, then one knows that the carbon points are not far enough separated, or if there is a flashing and sputtering the distance is too great, but a modern arc lamp works very steadily indeed. When arc lamps were at first used in public halls, they sometimes caused amusement by hissing, possibly during some political speech which was being delivered.

The intensity of light produced in an arc lamp is very great. The actual candle power is not easily determined, but it may be taken that an average lamp is from eight to twelve hundred candle power. It

will cost roughly from three to four pence to maintain two of these lamps for one hour. To produce the same amount of concentrated light at a given point with gas would require at least three hundred cubic feet, or about three times the cost.

When it is necessary to use a ground glass or opal glass globe, it must be remembered that these globes absorb a considerable proportion of the available light. Even an ordinary clear glass globe absorbs about 10 per cent. of the light, while ground glass may reduce the light by 30 or 40 per cent., and opal glass may practically shut off from 50 to 65 per cent.

An arc lamp placed at the focus of a large parabolic mirror gives us a most powerful light. If such a "search-light" be placed in a high lighthouse tower, the light may be visible for at least twenty or thirty miles on a clear night. There is an electric flash-light in St. Catherine's Lighthouse on the Isle of Wight, which is estimated at fifteen million candle power, and which should be seen from the coast of France in fine weather.

There would appear to be no limit to the brightness of the light which it would be possible to produce by increasing the size of the carbons and hence the current. Indeed it has been suggested that we might construct an arc light sufficiently bright to be seen by the inhabitants of Mars.

The light from an arc lamp is the nearest approach we have to sunlight, so much so that it was early called in to assist the photographer in taking photographs during dark weather or after sunset. The early photographs taken by electric light had a similar

appearance to those taken by magnesium ribbon or flash-light powder, there being too great a contrast between light and shade, producing a rather glaring effect. By arranging a number of arc lamps together, behind a large screen of ground glass, it has been found possible to produce a very excellent imitation of daylight. Photographs taken by such means cannot be detected from daylight exposures even by experts.

A single arc lamp throws a very severe shadow, so that it is usual to arrange the lamps in pairs, and thus cause the light from one to counteract the shadow of another.

It is interesting to note that the effect of the current upon the two carbon pencils in an arc lamp is quite different for each carbon. If the two pencils or rods are pointed to begin with, we find that very soon the leading-in carbon has lost its pointed appearance, and has become hollowed out in the centre like a crater, although the leading-out carbon still retains its pointed appearance while wasting away. Another interesting fact is that the temperature of the points of the carbons is very different. The leading-in carbon has a temperature at its crater of about 3500 degrees Centigrade, while the point of the leading-out carbon is a thousand degrees less. These remarks about the carbons only refer to lamps fed from a direct-current dynamo. If an alternating be used, then both the carbons will be similarly affected, each of them leading the current in and out alternately.

Considerable energy is required to produce an arc light. The rate of expenditure of energy in the small

space occupied by the arc is for a ten-ampere arc about two-thirds of a horse power.

There is a recent form of arc lamp in which all controlling coils have been dispensed with, and the carbons entirely controlled by the expansion and contraction of a hot wire. A spring tends to pull the upper carbon away from the other, while a flat steel wire acts in opposition to the spring. When the current is off the carbons are touching one another, but as soon as the current is switched on, and passes through the flat steel wire, this wire expands, and therefore allows the spring to raise the upper carbon, the wire having slightly relaxed its pull against the spring. In this way the arc is struck, and as the carbons waste away, the wire tends to cool and again pull against the spring, thus keeping the carbons at constant distance.

Owing to the continual volatilisation or wasting away of the carbons, it is necessary to replace them by new ones every fourteen or eighteen hours. This process, which is called trimming the lamp, is a decided disadvantage, as it runs up expenses, so that a natural desire arose to try and increase the life of the carbons. This has been done successfully during the last few years. What is the cause of this wasting away of the carbons? It is not by any means entirely due to the carbon vapour produced in the arc, for it is the leading-in carbon alone that supplies this. It is true that the leading-in carbon wastes away about twice as quickly as its neighbour, but this is chiefly due to the fact that its temperature is much higher, and if a to-and-fro or alternating current be used, so that the current enters by each

carbon alternately, the carbons will waste away at an equal rate. They will still waste away at such a rate that it is apparent more carbon is disappearing than the small quantity going to form the connecting bridge of the arc. The fact is, that the temperature is so high that some of the carbon is able to unite chemically with the oxygen of the atmosphere, which process we commonly call combustion. As the light is not dependent upon this combustion, we can afford to stop it if possible. We can at least limit the quantity of oxygen reaching the carbons, and this is done by enclosing them in a small globe, so that the arc is formed in this enclosed space. Only a small opening, where the lower carbon enters, is left to admit a limited quantity of air, and while a little air leaks in at this point, the heated gases leak out at the top of the enclosure. The small globe is quite apart from the ordinary outer globe. By these "enclosed arc lamps," it is possible to make the carbons last as long as from 80 to 150 hours, whereas the same carbons would probably want renewal in 18 hours, if used in an open arc lamp.

Possibly many readers will have noticed within the past year or so an arc lamp giving a much softer and yellower light than the bluish-white light of the ordinary lamp. This very powerful light is produced by what is called the "flame arc lamp," in which the cores of the carbons are made of certain salts, the exact composition of which is, I understand, kept secret by the makers. It is possible with these carbons to produce a much longer arc, exceeding half an inch, which if viewed through a

darkened glass has quite the appearance of an ordinary flame. In these lamps the carbons are usually both placed downwards, at an angle to each other, and the flame is made to take the form of a bow, being attracted out of its normal straight path by a magnetic field. The arc or flame is practically a conductor carrying an electric current, and is therefore affected by a magnet placed near to it. There would appear to be a great future before this class of lamp, its efficiency being very high, and the resulting light most pleasing.

It is interesting to note in passing, that one of the earliest uses of the arc lamp was made during the memorable siege of Paris by the Prussians in 1871, and in this connection I shall quote a few sentences from a paper written at that time by M. Saint-Edme :

"A battery was necessarily the generator employed, excepting in the case of the beacon of the Montmartre redoubt, which was provided with current from a magneto-electric machine.[1]

"The arc supplied with current from the magneto-machine was much more intense than one supplied from nitric acid batteries composed of fifty cells, since this machine was equivalent to one hundred of these cells. This beacon, skilfully handled, swept the whole plateau of Argenteuil with its rays, and plunged its beam even into the redoubt of Orgemont, situated more than six miles away as the crow flies. The Germans in vain tried to surprise our forts during the night ; the electric light kept good guard.

"Similarly the besiegers employed the voltaic arc to

[1] This machine would be constructed with permanent steel magnets to produce the magnetic field, as self-exciting machines were not then in use.

study our night works, or to illumine the fire of their batteries; the luminous beams sufficiently indicated that, on their side, the generator of electricity was of the magneto-electric order. The ability displayed in the installation and working of the apparatus proved also that the superintendents were learned electricians."

From the foregoing it will be seen that, in its very infancy, electricity was recognised as a powerful agent in time of war. What a boon our naval men find it to-day, to have a powerful searchlight on board a man-of-war!

Sir Humphry Davy, while acting as lecturer to the Royal Institution of London, not only exhibited the dazzling light of the electric arc, but also showed that a stick of charcoal might be raised to a white heat by passing a powerful electric current through it. The charcoal stick would not have a very long life at such a high temperature, and especially so if Davy used wood charcoal. However, the principle of a different kind of lamp was suggested by this experiment. It became apparent that if a very thin carbon conductor could be made, and then placed in a vacuum, so that no oxidisation or combustion could be possible, a very convenient electric lamp would be the result.

When the first suggestion of such lamps was made in the year 1852, there was really no demand for electric lamps, the practical dynamo not having been invented. But when the commercial dynamo was evolved some eighteen years later, several experimenters set to work, and in time produced practical

By permission of *Alex. Thomson, Paisley*

AN ELECTRICALLY-DRIVEN FIRE-ESCAPE

See page 65.)

incandescent or glow lamps. We are now quite familiar with these small glow lamps, but while we have become accustomed to the strange fact that we can produce a constant light without combustion, many will remember the early days of wonderment, when stories went round, telling of the new butler wasting a box of matches in the vain endeavour to light one of these lamps; or of the Irishman who said it beat him to see how the hairpin burned in the bottle. Then there was the story of a farmer visiting London, who on his return home complained that he could not sleep, because of the glaring light in his bedroom. When asked why he didn't blow the business out, he replied that it was impossible, as "they had the bit light shut up in a bottle." Nowadays even our children do not marvel at the strangeness of the glow lamp.

One of the great advantages of electric light is the ease with which it may be turned on or off, from any convenient part of a room. When the switch is left "off," there is a break made in the circuit leading to the lamp, so that no current can reach it, but when turned "on," the break is bridged over, and the circuit thus completed. The electric current from the dynamo finds an easy passage along the conducting wires, which are made large enough to conduct the current without becoming appreciably heated, but when the same current reaches the small carbon thread in the glow lamp, this part of the conductor offers such a great resistance to the passage of the current, that it is raised to a temperature of about 3500 degrees Fahrenheit, producing a very pleasant and soft light.

One great advantage in these glow lamps is that they do not require a very high voltage or pressure of electric current, and there is therefore no fear of fatal accidents from electric shock, if any one should get in contact with the wires, the person becoming momentarily a part of the conducting circuit. Another advantage is that this means of light is not accompanied by any noxious products, so that the decorations of a room do not become so dirty and tarnished as in a gas-lit room. However, the greatest boon, whether it is properly appreciated or not by the average man, undoubtedly is, that this form of light does not steal from us any of the precious life-sustaining oxygen, which we can ill afford to spare, and especially so if we insist on shutting ourselves up in rooms with closed windows and doors.

It will be of interest to follow briefly the manufacture of one of these glow lamps. The earliest experimenters made lamps with complicated details, which rendered them of no practical value. Edison and others made glow lamps with a thin platinum wire for that part of the conductor which was to be raised to a white heat, but the life of such a conductor was very brief, and the illuminating power not very high. The metal was also very apt to fuse when raised to the high temperature found necessary to produce the light. Inventors then tried to make suitable conductors or filaments of carbon, some using a cotton thread carbonised, others employing different kinds of grasses, paper, wood, lamp-black, tar, camphor, &c. Edison, in America, met with success in making a filament from strips of bamboo cane, baked in ovens till carbonised. In this country

Swan was successful with cotton fibres, soaked in sulphuric acid, and then raised to a high temperature till carbonised.

Nowadays the carbon filaments are made from a solution, one method being to dissolve cotton wool in chloride of zinc, till the liquid has a consistency similar to that of clear treacle. This solution is then forced from a jar through a glass tube, the end of which dips into another jar containing a settling solution of methylated alcohol and hydrochloric acid. The end of this tube which enters the settling solution is finished off in a fine point or jet, so that the solution squirted through it passes into the settling solution as a fine thread, and immediately congeals or coagulates. This continuous thread falling down in the settling solution, has the appearance of a fine gut string, such as used in a violin, or perhaps more like vermicelli. The material remains for some days in this settling solution. The size of the filament threads may be varied, by making the discharging jet larger or smaller. This flexible thread, when taken out of the settling solution, is carefully washed and dried, and then wound on to plumbago blocks or moulds to produce any desired form of filament; a simple loop, a curl, or a zig-zag.

The filament is now ready to be carbonised, and for this purpose the blocks with their thread-like windings are placed in pots or crucibles, and packed with finely-powdered charcoal in order to exclude all air, the packing also serving to keep the filament in position. These are then baked in ovens at a high temperature for a day and a night, and when taken out the filament is black and wiry but some-

what rough. These rough filaments are now carefully measured for thickness, sorted out accordingly, and cut to the required length. These filaments are to be placed inside a glass globe or bulb, and are to receive current from the outside, so that it is necessary to have the filament ends fastened to pieces of wire. As these wires have to be sealed into the glass bulb, they must be made of some metal which will expand under the influence of heat, at the same rate as glass expands. This is a very important point, for if the glass expanded quicker than the wires, then the bulb could not retain a vacuum, or, in other words, the outer air would find a passage into the bulb, between the wire and the loosely surrounding glass. Platinum fulfils this requirement better than any other metal, but as its cost is not much below that of gold, it is necessary to use very small pieces, just sufficient to enter the glass, and make a connection between the carbon on the inside, and the copper conducting wires on the outside. These little pieces are not only cut by a machine, but they have their ends neatly formed into tiny tubes or sockets, into which the ends of the carbon filament may be fitted. It would seem an almost hopeless task to attempt to make a proper joint between these fine filament ends and the tiny platinum pieces, and yet this is done in a most efficient manner. The most that one can do mechanically is to compress the tubulated ends of the platinum wire, after the ends of the carbon filament have been placed in them. In order to weld these two substances together, a connection or short circuit is made from one joint straight across to the

other joint, so that an electric current can be passed through the joints without going through the length of the carbon filament. No current is passed until the filament and the joints are immersed in a small tank of benzene or other suitable substance, when the current is turned on, the platinum joints become red hot, and carbon is chemically deposited, from the benzene, upon the joints, thus making complete contact between the carbon filament and the supporting platinum wires.

Every one knows what a very inflammable liquid benzene is, and how dangerous it is to bring a naked light near to it. It will therefore be clear that, during the foregoing operation, the red-hot joints must not touch the surface of the liquid, and that the current must not be turned on until the filament and joints are well immersed. I can imagine some one even thinking it a dangerous proceeding to raise a wire to a red heat while immersed in inflammable benzene; but there can of course be no combustion where there is no oxygen present. An experiment which demonstrates this fact, is to pass ordinary coal gas through a glass globe, leading it in by a tube at one side, and out by a second tube at the other side, where it may be allowed to burn as a small jet in the air. If we have previously arranged two wires leading into the globe, and connected them inside by a piece of platinum wire, we may now pass an electric current through this piece of platinum wire, and cause it to become red hot. Although this red-hot wire is immersed in a most inflammable gas, there is no danger of the gas catching fire, because there is no oxygen present with which the coal gas might

combine, or, in other words, there can be no combustion. I heard an aeronaut recently remark that the safest place for his petrol motor would be inside his balloon, right in the midst of the inflammable gas! He did not, of course, suggest that such an arrangement was possible in a flying machine.

Returning to the benzene process, every precaution must be taken to try and obviate the risk of fire, but despite the efforts of the most careful worker, the liquid does very often blaze up. The worker has in such cases merely to close a hinged lid over the tank, and the fire is at once extinguished, it having no fresh oxygen supply to continue the combustion. In case of accident, the workers are trained to keep cool, and to leave the rooms without any undue haste, and careful preparations have been previously made to deal with a fire at the first outbreak.

Before leaving the benzene tank, the filament is securely fastened to the leading-in wires; but the carbon filament is very irregular, and here again one might think it an impossible task to try and make this filament smooth and regular in thickness. This is done, however, in a most ingenious manner. The filament is placed under a small glass cover or receiver, from which the air is then all extracted by means of an air-pump. The glass vessel is then filled with hydro-carbon gas, and an electric current is sent through the filament, raising it to a white heat. This high temperature acts upon the surrounding gas, causing it to give up its carbon, which is deposited upon the hot filament. It might appear at first as though this would only make a thicker filament with the same irregularities as existed at the outset; but

nature has arranged matters much more conveniently. The thinner places of the carbon will naturally offer greater resistance to the current than the thicker places, and will therefore be raised to a higher temperature. At this higher temperature they acquire a greater grabbing power, as it were, and lay hands on more of the surrounding carbon, and thus the building up of the filament goes on until the whole length of the filament is of equal thickness. This process is termed "flashing," and after leaving this department the filament has a very respectable appearance—indeed, it is just as one sees it in the finished lamp.

It only remains now to seal the filament in the glass bulb, and then remove the air. The making of these glass bulbs is usually a separate industry, but when they arrive at the lamp factory they are not quite ready for the filament. The neck is first opened wide, so that the filament may be passed in later, and a small piece of glass tube is fused into the bulb, at the place where one sees a small nipple in the finished lamp. To any one not accustomed to see glass handled in the blow-pipe flame, it seems remarkable that such a process is so easy, and that the glass should become so pliable. The bulb looks rather strange now, with a short piece of glass tubing attached to its pear-shaped end; but this is merely a temporary appendage, and is to be used as the exit for the air when it comes to be extracted.

When the filament has been sealed into the bulb, leaving the ends of the two platinum wires extending through the glass, so that contact can be made with the conducting wires of the building, the lamp is then

ready for the process of exhaustion. It is first of all attached to a pipe leading from a mechanical air-pump, the small glass tube of the bulb being tightly fitted into a rubber connection leading into the air-pump pipe. After this pump has done its best to exhaust all the air, a second pump is brought into play. This pump, which is capable of producing a finer state of exhaustion, is called a mercury pump. The principle upon which this pump works is very simple, being merely an arrangement of long pieces of glass tubing, with a large quantity of mercury passing through the tube. The mercury is simply driven through by gravity, and is arranged not to pass in one continuous stream, but in drops or beads, one following another, and carrying away between these beads the air from any vessel attached to the glass tubing. Before being detached from this pump, a powerful electric current is sent through the filament, raising it to a white heat, and causing any gases in the filament to be expelled by the heat, and then removed by the pump, which continues to work during this process. The current passed through the filament during this process is much in excess of what the filament is to be subjected to in use, so that this process is a good test of the capabilities of the filament. If the lamp stands this test it is then sealed up at the junction of the bulb and the piece of glass tubing, the latter being removed, only leaving its mark in the form of a small nipple on the broad end of the bulb.

The lamp is now complete, except that it requires a suitable cap fixed on the neck, with contacts touching the two platinum wires. The lamps, however, are

not handed over to the public until they are each separately tested, and as some thirty lamps out of every hundred have to be thrown aside, the testing takes place before going to the expense of capping them. First of all they are tested to see that the air pumps have produced a good vacuum, for if they have failed to do so the life of the filament will be a very short one. This test is made by connecting the lamp to an induction coil, and if there is a glow produced in the bulb then it is known that the vacuum is not good, and the lamp cannot be passed. I shall not stop at this point to explain the action of an induction coil, as that subject will be better understood later. Those lamps which pass this test are then subjected to a powerful electric current, and overrun for some time; and if they stand this severe test, they can be relied upon to stand the normal current when in use. Their illuminating power, or "candle power," is then tested, and the lamp marked accordingly. Once more the lamp is tested for its vacuum, and if quite satisfactory it passes on to the capping department already mentioned.

In actual practice there are between forty and fifty different processes in the manufacture of the glow lamp; and if one has been inclined to grumble at the price of these lamps, one might rather wonder how it is possible to turn them out at such a low figure. It is only possible to do so by making them in very large quantities. A well-made lamp with a regular filament is cheaper in the long run than a less expensive lamp with inferior carbon, as the latter will require more current, and will soon eat up more than the difference of cost. Another mistake which

users are apt to make, is to continue to use a lamp after the days of its useful life are completed. Such lamps are only supposed to have a life of about one thousand hours—a very remarkable life for so fine a thread of carbon kept at so high a temperature. By treating the filaments—giving them a metallic surface—lamps are now being made to last a longer time. Some recent inventions aim at producing a greater illuminating power, by making the filaments of some of the rarer earths. The Nernst lamp has a small rod of rare metal oxide, which is brought to a white heat by the passage of an electric current. This small rod is not a conductor of electricity, as long as it is at a normal temperature; but when the current is turned on, it first of all passes through a short circuit which becomes heated, and in turn heats the small rod. As soon as the temperature of the latter rises to a certain point, the current is able to get through it, and in so doing it automatically cuts the heating or starting conductor out of the circuit. Hence when a lamp of this class is switched on, it takes quite an appreciable time to light up.

There is one other form of electric lamp which may interest the general reader, because of the "chamber of horror" effect it produces in all its surroundings. It is really a long vacuum tube with a small bath of mercury at each end, covering the ends of the wires, which are sealed in the glass. An electrical discharge has to pass from the one mercury bath to the other, and in so doing it vaporises some of the mercury, and this discharge passing through the mercury vapour gives a wonder-

fully powerful light, but of a most disagreeable and sickly colour, the red rays being entirely absent. The lamp may be of considerable service for special purposes where a powerful light is required.

The fact that electric incandescent or glow lamps do not vitiate the air of a room should make their use universal, and especially so in the small houses of our crowded cities. We cannot hope for this, however, till the price of the current is greatly reduced.

CHAPTER VII

ELECTRIC HEATING AND COOKING

Why electric heating is coming to the front—Recollections of early attempts—Electricity's advantages—Intense heat from transformers—Thawing frozen pipes—Electricity in the household—A new invention—The heating of houses—The real reason why luminous radiators are preferable—Hot-air bath—Davy and the electric arc—Arc furnaces—Resistance furnaces—Electrolytic furnaces—The production of aluminium—The production of a diamond

THE subject of electric heating and cooking has received very little attention till within recent years, and the reason has been that the various prices charged for electricity were too high, and therefore made the generation of heat by electricity so expensive that it could only be looked upon as a luxury. Electric current for heating purposes is now supplied in some parts of London at the rate of a penny per unit, so that this very clean and convenient method of producing heat has at last become quite practicable.

I remember being present, many years ago, at some of the early experiments in electric cooking, when it was found that, owing to the wasteful apparatus then used, and the high price paid for electricity, it really cost more to boil some potatoes than it cost to buy them. It was also found that it cost about three farthings to boil a small kettleful of water. To-day it is claimed that it only costs one penny to cook a large

By permission of *The Holland House Electric Mfg. Co., Ltd. "Prometheus System"*

Electricity provides a most convenient means of heating and cooking. Water may be boiled in the drawing-room or on the breakfast-table without the least fear of dirt, smell, or fire.

(See page 101.)

joint of beef, weighing eight-and-a-half pounds, or to grill thirty mutton chops, by electricity, while the same could not be cooked more cheaply by a gas oven. There is certainly more heat produced by the gas oven for a penny, but there is a far greater percentage of loss than there is with the electric heater. These considerations as to cost only apply, of course, to electric heaters supplied with current at a penny per unit. Until electricity is supplied generally at this figure, or even lower, as no doubt it will be some day, the progress of electric heating must necessarily be slow.

One advantage in electric heating is that it only uses current at the time of cooking, and does not require to be kept on as a coal fire does, but the same advantage is found in gas cooking. For cleanliness and convenience, however, the electric heater has no rival. There is no combustion, no foul gas, and the food is cooked in a pure atmosphere.

When Sir Humphry Davy produced his historic electric arc at the Royal Institution, he was much impressed by the very high temperature of the arc. We shall see later in this chapter that this source of heat has been put to practical use, but for general heating purposes the heat of the electric arc is too concentrated, affecting only a very limited area.

One cannot be working with batteries without observing that when a current is sent through a fine wire, the wire is very appreciably heated. If we give the current a very easy path by using a thick wire, then the heating effect will not be appreciable ; but if we offer any considerable resistance to the current, the conductor immediately becomes hot. If we join

some pieces of fine silver wire to some pieces of the same thickness of platinum wire, making alternate links of the two metals, we find on passing a current of electricity along this conductor that the platinum becomes red hot, while the silver pieces joining them do not. We therefore see that the platinum wire is offering more resistance to the current, or, in other words, that the silver is the better conductor. If we take a piece of the same silver wire and pass a more powerful current through it, we then find that the silver becomes red hot. We can therefore balance matters to suit our purposes, for we may lead the current along conducting wires of sufficient size to carry the current without any appreciable heat being generated, and then by offering a path of greater resistance at some particular point, say inside a cooking utensil, we can get the current to produce heat.

It is therefore quite an easy matter to heat a metallic resistance by an electric current, and to maintain it at a fixed temperature. A spiral formed by a suitable wire may be placed in a vessel of water, and an electric current sent through the wire till it brings the water to boiling-point. A more convenient method is to arrange metallic resistances in the sides and bottom of a pot or kettle. A wire offers only a very small heating area, so that strips of thin sheet-metal are better; in some cases a metallic resistance is merely deposited or painted on to strips of mica. The metallic conductors may be embedded in clay or enamel, which serves to insulate them, while for some purposes asbestos or mica may be used as the insulators.

In describing a power sub-station in chapter iv., it will be remembered that I mentioned large trans-

formers for "stepping down" the current received at a high pressure, and that in these transformers the current passes through large coils of wire. If one enters the chamber in which these transformers are at work, one might naturally inquire the reason for keeping the room at such a high temperature, as it feels quite like a boiler-house. But there is no heat being intentionally produced; it is the result of the resistance offered by the coils of wire to the passage of the electric current. The resistance is so great that all this heat is generated, although the coils are kept as cool as possible by immersing them in oil, while a ventilating fan keeps drawing away the heated air from the transformer.

Some electric-power companies keep special transformer arrangements for thawing frozen pipes, and these have proved very satisfactory, often saving excavations, and restoring the water supply quicker than could be done by any other means.

Electric heating is very suitable for household purposes, because it is absolutely clean, safe, and odourless. Water may be quite conveniently boiled on the breakfast or afternoon-tea table; one merely turns a switch and the heat is immediately applied. It is also possible to regulate the heat by means of a special switch. I can remember, many years ago, being impressed by the convenience of electric heating, long before it was considered commercial. While staying as a guest in a country house in Switzerland, I saw for the first time an electric heater, which consisted of a neat little electro-plated dish standing on the dressing-table. One merely turned the switch on, and shaving water was ready in a minute; no com-

bustion, no smell, no trouble. Nowadays one sees many utensils heated by electricity, such as domestic irons, curling-tongs, felt bed-warmers, cigar-lighters, &c. One of the latest patents in this department relates to the heating of the handles of automobiles, so that the chauffeurs may not be troubled with benumbed hands on cold days ; and it is claimed by the patentee that this heating can be done at a cost of one penny per working day.

One very large hat factory in America, which turns out four thousand hats per day, has installed electrically-heated moulds, &c., in place of gas heaters, and this has proved very satisfactory to the masters, and must be much pleasanter to the workpeople.

In addition to the foregoing methods of producing heat in metallic resistances, there is a recent invention in which the current is made to pass through a powdered resistance, bringing the powder to a red heat. The resisting material has been named kryptol, and is composed of a mixture of graphite, carborundum, silicates, and clay ; the composition being used in a granular or powdered condition. This powder may be spread upon a flat stand or table, having carbon conductors or electrodes at opposite sides, so that the current has to pass from the one to the other through the kryptol. This material offers so great resistance that it is raised to a red heat, which may be used for cooking with ordinary pots and kettles. If this red-hot powder is exposed to the air there must be some combustion, as graphite and carborundum will oxidise, but the chemical combination with the oxygen of the air is so very

small that one layer of kryptol is said to serve for three months of daily use. It is remarkable that this resisting powder may be raised to a very high temperature, and still remain in the same chemical condition. This method of generating heat provides a very convenient means of bringing crucibles to a high temperature in the chemical laboratory.

In this country we have not as yet any very large industrial applications of electric heating, except in the electric furnaces hereafter described, but in America we find the Natural Food Company of Niagara baking bread and biscuits on a very large scale with electric ovens, thus saving the labour of handling coal, and serving to keep the bakery clean and pleasant.

One may heat a room by an electric heater on the metallic resistance principle, attaching the wires to large metal plates in order to give a greater heating area, but such heaters are essentially air warmers. The air passes over the heated surfaces, and when heated it rises upwards, so that the air of the room becomes heated from the ceiling downwards, requiring a long time to become heated down to one's feet, if indeed it ever reaches this point. It is just like a hot-water pipe system, which is dependent upon the air to conduct the heat throughout the room. In addition to this defect, a heater such as described has not a cheerful look; one would soon miss the open fire. It is not only the cheerful appearance that one would miss, for a coal fire does not heat a room by merely warming the air, indeed the most of the air that comes in contact with the fire is speedily robbed of its oxygen, which,

along with the remaining constituents, is sent up the chimney in combination with the carbon of the coal, &c. A fire radiates heat in the same manner as our benefactor the sun does. This is not a material conduction, as is the case with the air-warming apparatus ; it is an ether disturbance, called radiant heat.

There are electric heaters, which imitate the sun and the coal fire, and these radiators are on the principle of a large incandescent or glow lamp. There is a much larger and heavier carbon filament or conductor, and this is placed inside a long frosted glass bulb, from which the air is then exhausted, in order to prevent the combustion of the carbon conductor. Several of these long glass bulbs are mounted on a stand with a reflector behind. At first it was found impossible to get the carbon filaments to withstand the heat, but it was discovered that their breakdown was really caused by the additional heat thrown back by the reflector behind them. When these reflectors were altered, so that the heat was directed past the conductors, this system of heating became an established success. The one thing now required to bring these radiators into general use is a reduced price for electricity. Think of the convenience of being able to carry your "fire" from one room to the other at will! Then there will be no early rising to kindle the fire, no dust and ashes to remove. The radiator will light the moment you merely turn on the current. These radiators have a nice cheerful appearance, but what is far more important, they directly warm the room and the articles in it by

radiating the heat throughout the room, as is the case with a coal fire. Of course, a gas stove also radiates the heat, but if one realises that a gas stove is hard at work incessantly robbing the air of a room of its life-sustaining oxygen, then nothing will prevent the substitution of an electric radiator, when the cost does not exceed that of the older rival.

In cases where therapeutic effects can be produced by high temperatures, electricity comes very conveniently to the medical man's aid. The patient may thus have a hot-air bath at a temperature of 300 degrees Fahrenheit, without suffering any inconvenience, whereas the temperature of a Turkish bath, with its water-laden atmosphere, rarely exceeds 175 degrees Fahrenheit.

As mentioned earlier in this chapter, it was the intense heat of the electric arc which appealed so forcibly to the great chemist, Sir Humphry Davy. He said that the metal platinum melted in the electric arc just like wax in a candle flame; to-day we have practical electric furnaces. In an arc furnace the resistance is, of course, merely a gas or vapour, as in the arc lamp, but when the heat is conserved by enclosing the arc in a furnace of material which is a bad conductor of heat, the temperature obtained is sufficient to melt the most refractory substances. A temperature of 7000 degrees Fahrenheit, or 4000 degrees Centigrade, has been attained in one of these arc furnaces.

It is claimed for the electric furnace that it will some day replace its predecessor the blast-furnace,

but for the present its cost is considerably greater. Even where the generating power is got from waterfalls, there is excessive expense in carrying the iron ore and in returning the ingots. When electric current can be more cheaply distributed the electrician's hopes may be realised. The electric furnace is at present most useful for doing work where exceedingly high temperatures are required, as in the production of carborundum, which is only surpassed by the diamond in hardness, and also for smelting very refractory substances that will not easily respond to temperatures produced by other means. Carborundum is produced by heating a mixture of silica and carbon, or, in other words, sand and coke.

In the arc furnace the substance to be treated may either be placed in the immediate neighbourhood of the arc, or it may be made to form one of the poles of the arc. We see therefore that we have electric furnaces on the simple principle of the electric arc as used also in electric lighting. We also have electric furnaces on the same principle as the glow lamp, in which the electric current heats a continuous conductor. Such furnaces are called resistance furnaces, and may have a suitable resistance of carbon raised to a very high temperature by the current, which then imparts the heat to the raw material, or it may be arranged that the raw material to be treated forms the resistance between the two furnace terminals.

We now have large industries using electric furnaces for the production of calcium carbide, from which acetylene gas is obtained, also for the manufacture of phosphorus, glass, carborundum,

graphite, &c. &c. The electric furnace is also of great service in the chemical laboratory, enabling the experimenter to produce a very high temperature in a most convenient manner.

In some processes, such as the production of aluminium from the compounds in which it is found in the earth, the electrically produced heat not only acts upon the material under treatment, but the electric current passing through the material assists the chemical action, so that a furnace used for such purposes is called an electrolytic furnace, signifying that there is a chemical effect due to the current. This is really the phenomenon which interested Davy most of all, for by this means he was able to produce certain metals not previously known in a free state.

The subject of electrolysis will be dealt with in the succeeding chapter on electro-chemistry, but it may be of interest to note here that, by means of the electrolytic furnace, aluminium is now produced at one-twentieth of its former cost. The metal aluminium is very abundant in nature, being present in nearly every variety of clay, but its relatively small use in manufactured articles is due to the expense of extracting it from its compounds. It is most easily extracted from its hydrated form, known as bauxite. This subject, however, rather overlaps that of the following chapter, so will be referred to again therein.

Before closing this chapter it may be of interest to note that electric welding is making considerable progress in many industries. The heat is produced by the electric arc, which may be taken to any desired places, as long as connection is maintained

with a generating station or dynamo. Simple electric welding machinery may now be found welding rails, chains, and wire fencing, while in connection with other manufactures, such as rings, steel tubes, wheel rims, tools, &c., electricity is making efficient welds.

The intense heat obtainable from electricity has been well demonstrated in the production of diamonds by means of the electric furnace. It so happened that a piece of a large meteorite, which had reached this earth from some part of the surrounding universe, was found to contain small diamonds embedded in the iron ore. There were not only black diamonds, but some transparent ones of crystalline form. These were all of very tiny size, but, nevertheless, real diamonds. This discovery set the chemist wondering if it would be possible to copy nature and produce similar diamonds in the laboratory.

It had already been found possible to produce rubies by applying intense heat to alumina (the material of ordinary clay) and then crystallising the molten alumina. Rubies of ten and fifteen carats had been produced in this way, and so it was considered worth while making a serious attempt to produce diamonds. It was evident that nature had used some immense pressure in crystallising the hard diamonds in the meteorite, and so the chemist must imitate nature in this respect. In the meteorite the outer parts had no doubt been quickly cooled, whereupon the molten interior had suddenly expanded and produced the necessary pressure.

How is the chemist to produce in his laboratory this work of nature? We all know that the costly diamond is composed of the same elementary sub-

stance as we find in our household coal, and so we are not surprised to learn that he has provided some small grains of charcoal or carbon. Placing some iron in a small crucible, he raises it to an intense heat in the electric furnace. When the iron is in a molten condition he drops in the grains of carbon, and covering up the furnace he dissolves the carbon in the iron. The crucible is now at a temperature of about 5000 degrees Fahrenheit, and he must employ some means of suddenly cooling it, in order to bring about an immense pressure in the interior of the molten mass. If he dips the crucible into cold water, he finds that a gas immediately forms on the outside of the crucible, and makes a jacket, as it were, which prevents the heat from escaping quickly. He must therefore adopt some other means. He meets with success when he uses a bath of molten lead for cooling the crucible. It will seem somewhat strange to the layman to hear of a bath of hot molten lead being used as a cooler. Possibly it reminds him of the crank who put his feet in hot water to keep them cool. We must remember, however, that the crucible leaves the electric furnace at a temperature of about 5000 degrees Fahrenheit, whereas the temperature of the melted lead is only 606 degrees; a drop of over 4000 degrees.

The accompanying photograph (page 110) shows the crucible being suddenly plunged into the molten lead, causing a pyrotechnic display of bright sparks. The sudden cooling causes the molten iron in the crucible to solidify. An outer casing will immediately form, whereupon the molten centre will suddenly expand, producing the necessary pressure, and the

carbon is found to have crystallised. When the whole mass has cooled, the iron is dissolved with acids, leaving the carbon in the form of small diamonds, some black and others transparent, but all of mere microscopic size. Nevertheless they are real diamonds, and we may some day be able to perform the same experiment upon a much larger scale.

By permission of *The Scientific American*

THE PRODUCTION OF DIAMONDS BY THE ELECTRIC FURNACE

The crucible, containing its very highly heated material, is taken from the furnace and plunged into a bath of molten lead in order to quickly cool the crucible.

(See page 108.)

CHAPTER VIII

ELECTRO-CHEMISTRY

The intimate connection between electricity and chemistry—A wrong conception of Volta's pile — How water is decomposed — The advantage of chemical symbols — Some memorable experiments by Davy—Birth of a new metal—An amusing reminiscence—Other new metals discovered—Electro-chemical industries—The production of carbonate of soda and bleaching powder — Aluminium — Interesting applications of electro-chemistry — Metal-refining by electricity—Electro-plating and electro-typing—Ingenious forms of primary batteries—Dry cells—Electro-chemical reactions—Invention of the accumulator — Its general use — A most patient experimenter

If one looks at any form of electric battery, it is quite apparent that there must be some intimate connection between electricity and chemistry. We have the chemical action in the cell or battery, producing an electric current in the wire connecting the elements of the cell; we therefore see chemical energy transformed into electrical energy. It is only reasonable to expect that the converse will also be true; that electrical energy will give rise to chemical energy. The latter phenomenon was really observed before the former, for it was found that the electric current from a voltaic pile would cause water to split up into the two gases of which it is composed. It is true that this phenomenon was produced by electricity which was generated by chemical means, but the effect of the voltaic pile was not then recog-

nised as being due to chemical action. It was supposed that the electric current resulted merely from the contact between the two kinds of metal used in the pile, these metals being by nature in different electrical conditions. These early experimenters supposed that the separating cloth, which was moistened with acidulated water, merely acted as a conductor, and that the current was set up between the copper and zinc discs, which were in contact with each other. The true explanation really was, that the chemical action of the acidulated cloth on the zinc set up an electric current between the zinc and the copper disc on the other side of the cloth; not the copper and zinc which were touching each other. These early scientists therefore called the copper and zinc which were together a pair or couple, whereas the true couple is a copper and zinc on either side of the moistened cloth. When Volta afterwards placed the two elements in a vessel containing acidulated water, as explained in the Introduction, then the intimate relationship between electricity and chemistry became evident.

Without considering the science of the matter at present, leaving that to be dealt with later on, it is clear that we have a very useful chemical property in electricity, acting as a decomposing agent. There are now many chemical industries dependent upon this phenomenon. Sir Humphry Davy recognised the possibility of this new-found agent, although in his time most ridiculously exaggerated statements had got abroad. Some experimenters declared that many chemical compounds had been produced by merely passing an electric current through pure

water. Davy, however, was convinced that in electricity he had a valuable assistant.

As already mentioned, the first electro-chemical observation made was, that an electric current in passing through water gradually decomposed it, freeing the oxygen and hydrogen gases, of which it is composed. Our two fellow-countrymen, Carlisle and Nicholson, who discovered this in 1800, while experimenting with a voltaic pile, were therefore the first to observe a very important fact. When we come to consider the science of this subject later, we shall find that the electric current cannot really decompose pure water, it being found necessary to add a little acid or salt, but in effect we get the water to decompose, and we have left in its place hydrogen and oxygen gases. The simple apparatus for obtaining this result is shown in the accompanying photograph (page 128).

Looking at the photograph, it will be seen that this water-decomposing apparatus, or voltameter, is very simple. In the centre is seen a long tube with a bulb at the top. This tube and bulb merely act as a reservoir for holding the water, which also fills the two upright limbs, which are provided with stopcocks at their upper extremities. These are really the only extremities the tubes have, as they and the base reservoir tube all merge into one another at the base. A wire is seen leading into the base of each of the two upright limbs, and each wire connects to a little platinum plate or electrode inside. The apparatus is filled by means of the central tube, acidulated water being poured in at the bulb. Acidulated water simply means water with a little sulphuric or other

acid added to it. When the two upright tubes are filled, their stop-cocks are closed, and as soon as an electric current is sent through the water from the one electrode to the other, bubbles of gas are seen to rise from each electrode. As the electrodes are each placed immediately under one of the upright tubes, the bubbles of gas rise in the two separate tubes. The gases therefore collect at the tops of the tubes, where the closed stop-cocks are. We soon notice that there is more gas being given off at the leading-out electrode than at the leading-in wire. The former electrode is called the kathode, while the leading-in electrode is named the anode, but I shall continue to use the clumsier terminology, as I find some people have difficulty in remembering the electrodes by their proper names. If we measure the space occupied by gas at the top of the leading-in tube, we shall find it is only about half of that in the other tube, and knowing that water is composed of two parts of hydrogen gas to one part of oxygen, we can tell which is the hydrogen and which the oxygen. Taking a lighted taper, we can burn the hydrogen gas as we allow it to escape from the tube over the leading-out electrode. With a little trouble we can collect the gas from the other tube in a bottle, and if we then insert a match with a red-hot end, the match at once breaks into flame, and burns with a much brighter light than it does in ordinary air. This is a clear proof that the gas is oxygen, the necessary supporter of combustion. This voltameter is, of course, merely a convenient means of collecting the gases separately. Water, if placed in an open basin, will decompose just as well when a current

is passed through it, but then the gases pass off into the air. In referring to the spaces occupied by the two gases in their respective tubes, I used the words "about half" as much oxygen as hydrogen. It may have occurred to some reader, why not exactly half as much, as the air is composed of twice the volume of hydrogen to that of oxygen? There is certainly only twice as much hydrogen given off by the one electrode as there is oxygen by the other, but yet the oxygen is found to be less than half the hydrogen, the reason being that the oxygen is more soluble in water, so that some of it has been taken up by the water.

In chemistry there are symbols used for all the elementary bodies, such as H for hydrogen, O for oxygen, C for carbon, and so on. In making up a "shorthand" of this kind, it was found impossible always to use the first letter of the name, as more than one substance happens to begin with the same letter. The letter C has been used for carbon, so that we must find something different for copper. The Latin word for copper is *cuprum*, so that Cu will serve to represent copper. In the same way, the letter S having been used for sulphur, the letters Ag are made to represent silver, the Latin for which is *argentum*. The symbol for water is therefore H_2O, signifying that it is composed of two parts of hydrogen to one of oxygen, and this fact is demonstrated by the voltameter just described. The sulphuric acid, which we added to the water in the apparatus, has as its symbol H_2SO_4, because it is composed of two parts of hydrogen, one of sulphur, and four of oxygen.

A few years after this discovery of the decomposi-

tion of water had been made, Davy set about making some experiments which will remain memorable for all time. The substances potash and soda were at that time believed to be simple bodies or elements, although it had been suggested by a great French chemist that they were compound bodies. He had tried, however, to decompose them by all methods then known, but they had remained obstinate. Davy summoned electricity to his assistance, and sought to decompose them in a similar manner to that in which water had been decomposed. He placed a small piece of potash on a tray or disc of platinum metal, and connected this by a wire to the one terminal of his battery. In other words, he made the platinum tray one of the electrodes. He then brought a platinum wire from the other terminal of his battery, and made the end of the wire touch the surface of the potash. The end of this wire was then the second electrode, and the potash was in contact with both, so that a current could pass from the one electrode to the other by going through the potash. Recognising that it would require considerable energy to decompose this substance, which had defied all previous methods, Davy used a powerful battery of two hundred and fifty cells coupled together. When this powerful current was turned on, the potash melted at the points where it touched the electrodes. From the upper surface gas was evolved, while on the lower surface there appeared small beads or globules of a bright metal, somewhat like mercury in appearance. As Davy watched this decomposition, he witnessed the birth of a new metal, which had till that hour been securely locked up in

the compound substance called potash. At last it had been freed by the chemical effects of the electric current. To this metal was given the name potassium. This new-born metal was found to have very strange properties indeed. If a small piece of it be dropped into water, the metal will actually burn, giving forth light and heat, and producing a slight explosion.

I remember, when a boy, having some amusement by cutting up a little potassium into small pieces and placing them in a bottle filled with naphtha, which keeps the metal in its normal condition.[1] Putting the bottle in my pocket, I went out one dark night, when a drizzling rain was falling, and making my way along a quiet suburban street, I chanced to come across a constable, evidently very deep in thought, and apparently riveted to the pavement. After passing him, I carefully took some of the potassium from my pocket and threw it well out into the centre of the street. In a few moments there was a mysterious series of small explosions from the centre of the street. I saw the constable go very cautiously towards the scene of the explosion, evidently fearing a recurrence from the same spot. I deemed it wiser, however, not to wait and discuss matters, so left the perplexed constable to think the matter out for himself. It may be that till to-day he believes he witnessed a work of the evil one, which no doubt he did indirectly.

But to return from this trivial incident to the subject from which I have wandered, we find that

[1] The reason why the naphtha acts as a preservative is that it contains no oxygen, and there can therefore be no oxidisation or combustion. When the potassium is put in water it is able to very energetically combine with the oxygen in the water, hence the combustion.

Davy succeeded not only in decomposing potash, but also when he treated soda in the same manner, he produced another metal which he named sodium, and which has the same strange burning properties as potassium.[1] To the uninitiated it is very strange to see a candle set alight by touching it with a piece of wet wood, and yet the youthful conjuror may do so, by previously secreting a small piece of potassium in the wick.

Davy's electro-chemical achievements did not end with potassium and sodium, for in the same year he produced three other metals, barium, strontium, and calcium, from their respective compounds; the last mentioned being extracted from lime. Later on he obtained magnesium, but he failed to extract a metal from the earth alumina, which, however, was achieved about a generation later. In the electrical decomposition of all these compounds, it is the metal which appears at the leading-out electrode, and the gas or other non-metallic constituent which collects at the leading-in wire. Davy's assistant and successor, Michael Faraday, gave the name of "electrolysis" to this electric analysis or decomposition, the Greek word *lysis* meaning a loosing. The substance through which the electric current is passed, or, in other words, the substance under treatment, is called the electrolyte. In speaking of this electro-chemical process, I have already used the word electrolytic action, and I also remarked that the leading-in electrode was termed the anode, while the leading-

[1] These peculiar metals, potassium and sodium, exist in our own bodies in combination with other elements. There is about twice as much of each of these metals as there is iron in our human framework.

out wire is called the kathode. I shall continue, however, to use the more descriptive titles.

Davy and Faraday laid the foundations upon which we have now built large electro-chemical industries. The total driving power used in these industries for generating the necessary electric current will probably amount to between one quarter and one half million horse-power, the bulk of which is obtained from waterfalls.

In one industry, called the Alkali and Chlorine Industry, a solution of common salt or brine is electrically decomposed, or electrolysed into sodium and chlorine. The sodium appears at the leading-out electrode, but not as a metal. It immediately unites with carbonic acid gas, which is injected into the apparatus, and the result of the combination is carbonate of soda, which is one of the most important products in the alkali industry. The chlorine gas, which is evolved at the leading-in electrode, may be made to combine with lime, and thus form chloride of lime, perhaps better known to the general reader as bleaching powder. The chlorine gas may be made to form chlorate of soda, or chlorate of potash, both of which are very saleable chemicals.

Those of us who as boys dabbled in chemistry, will remember the eagerness with which we produced oxygen gas from this chlorate of potash. We mixed it along with some black manganese dioxide, and then heated the mixture in a glass flask, leading off the gas by means of a glass tube, and then collecting the gas as it bubbled up through the water in a basin. One is not to infer that this is the chief use of chlorate of potash; it is largely used in the

dyeing and calico-printing trades, in the making of lucifer matches and fireworks, &c. &c.

There are several forms of electrolytic cells used in the alkali industry, but the easiest to describe in words is that known as the diaphragm process. A large cell is made, with a porous dividing wall or diaphragm separating the two electrodes. This does not prevent the electric current getting across from the one electrode to the other, but it serves to keep the products quite separate. The leading-in electrode is usually made of platinum or carbon, but the leading-out electrode may be made of iron or copper. This one branch of electro-chemical industry uses about 50,000 horse-power per annum in driving its dynamos to supply the electrolytic cells with current.

The principle of all purely electrolytic processes is the same as that explained in connection with the decomposition of water, so that we need not go into further detail here. It may be remarked in passing, that the electrolysis of water is carried on commercially, the oxygen and hydrogen being used subsequently for various purposes.

Electricity has no rival in some electro-chemical industries. In the alkali industry, already described, electricity keenly competes with the older chemical processes, but in such processes as the production of the metal sodium, electrolysis has no rival. This process is practically Davy's original experiment on a larger scale, fused caustic soda being electrolysed between iron or nickel electrodes.

The extraction of aluminium from its compounds, as briefly mentioned at the close of the preceding chapter, is really done by a combined process of

electric heating and electrolysis. Aluminium was originally obtained by purely thermal and chemical processes, but the cost of production was so great that the metal could not be used for everyday purposes. With the introduction of the electrolytic furnace, the price has fallen from 20s. to 1s. per lb. Under the former condition of manufacture, aluminium was hardly ever seen in the ordinary walks of life, but now there will be at least 18,000 tons of aluminium electrically produced every year. If the subsequent refining processes can only be reduced in cost, there will doubtless be a very great increase in this production.

Some of the applications of electrolysis I shall merely mention in passing. There is electro-dyeing, electric bleaching, the purification of sewage, electric tanning, and the rectification of alcohol. Electric tanning calls for special mention, for by the introduction of electrolysis, some processes formerly occupying months are now performed in days. The stripping of tin from tinned iron scraps or waste is an important electro-chemical industry; one works alone treating over 10,000 tons of scraps per annum. Another important application of electrolysis is the extraction of gold from the "tailings" or refuse from the stamp mills. Formerly this was thrown away as worthless, but now, in the Transvaal alone, over 1,000,000 tons are treated electrically every year. Gold and silver are also separated by electrolysis, and base bullion is electrically refined.

One of the most recent electro-chemical industries is the extraction of nitrogen from the atmosphere, the gas being used to make nitric acid. It is stated

that one factory in Sweden produces one ton and a half of nitric acid every day in this way from the atmosphere. The electric arc plays an important part in this process.

Electricity assists in the making of good copper conductors to be subsequently used for carrying electric currents. More than half the total output of copper is used for making electrical conductors, and as any impurity in the copper interferes with its conducting powers, it is most important to have pure copper. Even less than 1 per cent. of carbon reduces the conductivity of copper by about 30 per cent., while a mere trace of arsenic reduces it to little more than half the conducting power of pure copper. Thus the electrolytic refining of copper is now a very important industry, treating about half a million tons of copper annually. Among the impurities electrically deposited from the crude copper are found silver and gold, which are secured and realised.

The general principle of electro-refining of copper is very simple. A cast plate of the crude copper is suspended in a bath of copper sulphate solution, having a little sulphuric acid added to the liquid. The crude copper plate is to be the leading-in electrode for the current, while a thin sheet of pure copper is to be placed in the solution to act as the leading-out electrode, the two electrodes being put very close together. The electric current in its passage from the crude copper plate to the pure copper electrode really decomposes the copper sulphate solution, depositing its copper upon the leading-out electrode. For the present we may

imagine the electric current taking the copper from the solution, and adding it to the pure copper sheet, while the remaining constituents of the decomposed solution help themselves to some more copper from the plate of crude copper. In this way the crude copper diminishes, while the pure copper plate increases, the impurities being precipitated in the solution, which must be purified or replaced by fresh solution from time to time. Gold and silver may be refined by a process similar to that just described.

The foregoing process is in reality electro-plating, for we may imagine the thin sheet of pure copper to be plated with copper indirectly got from the crude copper plate. It was not necessary to have the leading-out electrode made of pure copper, or of copper at all. Any metal would have served as a surface for depositing the pure copper upon, but as the intention was to produce a pure copper plate, it was, of course, necessary for that particular purpose to use a piece of pure copper as the leading-out electrode. If we had used a piece of iron for this electrode, then we should have had the iron enclosed in a deposit of pure copper, or, in other words, we should have had a copper-plated piece of iron. We may therefore attach an article, made of any cheap metal, to the leading-out wire, and plate it with copper. If we use a piece of silver as the leading-in electrode, and make the electrolyte a solution of the double cyanide of silver, then we produce a deposit of silver upon any article forming the leading-out electrode. In a similar manner we may plate articles with gold or nickel, using suitable electrolytes which contain these metals in solution.

The electro-plating industry is now a very large business, dynamos being, of course, used for generating the necessary current for all large electrolytic processes, although one may easily electro-plate on a small scale by means of a chemical battery. The amateur's results are usually rather rough, unless he happens to be an adept at polishing. Electro-plating by means of primary batteries was successfully accomplished almost a century ago.

It is not necessary that the object to be plated should be made of metal ; it is only required to have a surface that will conduct electricity. A mould or cast made of any plastic material may have its surface made conducting by the application of graphite, &c. In this case the electrically deposited metal will not adhere very firmly to the object, as is the case in electro-plating upon a metal object, but when a mould has been electro-plated or, to use the word more common in this particular connection, electrotyped, the mould is removed or broken away, and the thin plating is backed with some metal alloy. If a mould be taken of an engraved printing block, or of a set of type, then this mould may be electroplated or electro-typed, the result being practically a facsimile of the original. This process is largely used in the printing trade, to produce a duplicate of the type set up by the compositors, thus saving the locking up of large quantities of type for printing purposes. The reproduction of medals, coins, statues, and works of art, is also achieved by this process of electro-typing.

The subject of chemical batteries naturally falls

under the title of this chapter, but it would not be of general interest to go into much detail, so that only a few remarks concerning these will be made here. The scientific consideration of what really takes place in a battery, in order to set up an electric current, will be left over till later.

Volta's first electric cell, with its plates of copper and zinc immersed in acidulated water, has already been mentioned, and also the modern cell with carbon and zinc immersed in a solution of sal-ammoniac. The early experimenters soon found Volta's cell very intermittent in its action, so they set about making cells which would keep up a more regular flow of current. The irregularity was found to be due to hydrogen gas gathering on the copper plate, for if we have a current of electricity flowing through the acidulated water, we must have a decomposition of the water accompanying it. At the zinc plate, oxygen gas would gather, but as soon as it appeared it would unite with the zinc and form zinc oxide, whereas the hydrogen and copper had no grabbing power for one another. We may therefore picture the copper plate as gradually being electro-plated with a coating of hydrogen gas, so that in a very short time the elements of the battery would be practically zinc and hydrogen, instead of zinc and copper. The difference of electrical condition between zinc and hydrogen is very small indeed, and from that cause alone the current would be weakened, but in addition the coating of hydrogen gas offers considerable resistance to the passage of the electric current, so that the simple voltaic cell could not keep up a steady current for many minutes consecutively. It was suggested to try and remove the

hydrogen gas as quickly as it was formed, or better still, to try and prevent its formation. One early idea was to keep brushing the hydrogen off the plate as it collected, but this proved a rather clumsy arrangement. If, however, the copper plate, or element, upon which the hydrogen gathers, is placed in a liquid rich in oxygen, the two gases unite together, forming water, and thus keeping the plate clear. This process is known as depolarising.

The pioneer cells made on the foregoing principle were Daniell's, Grove's, and Bunsen's, the first mentioned being invented in 1836, and the other two following closely. It will be sufficient for our present purpose to describe briefly the first of these. In Daniell's cell the troublesome copper plate was placed in a solution of copper sulphate, while the exciting liquid (sulphuric acid and water) was placed with the zinc plate inside a separate vessel, this being a porous pot made of unglazed earthenware. This porous pot, containing the acid and the zinc element or plate, was now placed inside the vessel with the copper sulphate solution and the copper element. The two liquids could not mix, but when the acid commenced to act upon the zinc, the hydrogen gas made its way through the porous pot with the object of reaching the copper plate. Before reaching the copper plate, the hydrogen must pass through the copper sulphate solution. This liquid is rich in oxygen, as can readily be seen from its symbol, which is $CuSO_4$. As soon as the hydrogen emerges from the porous pot, and enters the solution of copper sulphate, the hydrogen gas chemically unites with the oxygen of the solution, and it therefore never reaches the copper plate. In this way the copper

plate is kept clear, and a much steadier current is obtained from cells of this class. The simple chemical cell with its zinc, carbon, and sal-ammoniac is, however, quite good enough for bells or telephones, where there is only a short call made upon its energy at intervals. With the advent of portable storage cells or accumulators, there is really little use now for these depolarising cells, except for certain experimental work, or for electro-plating on a small scale.

Dry cells have already been mentioned in the Introduction, and these are simply primary cells in a more portable form, the electrolyte being made in the form of a damp paste in place of a free liquid. In these dry cells there is usually a rod of carbon in the centre, surrounded by a paste containing a depolarising liquid, and the exciting liquid is also contained in a paste which is in contact with a zinc cylinder, generally forming the outside of the cell itself. The word "dry" is, of course, only used in contradistinction to the ordinary free liquid cells. A really dry cell would be useless.

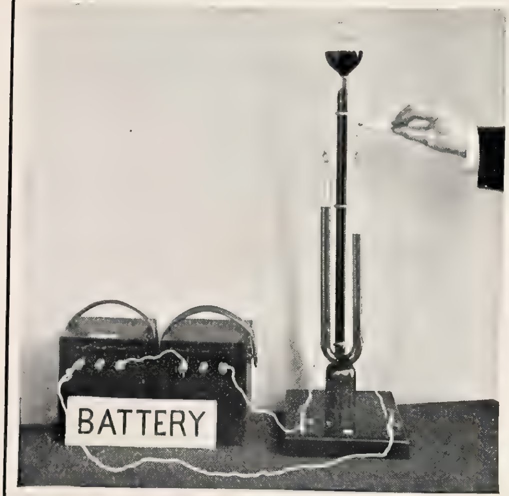
In connection with the electro-chemical industries, we saw that an electric current produced chemical changes. Then again we see from these primary cells that certain chemical conditions produce an electric current. It is therefore quite reasonable to argue that if we set up chemical action by means of an electric current, there may be a reaction, and we may find that the altered chemical conditions will in turn set up an electric current. A simple experiment will make the matter quite clear.

Reverting to the decomposing of water as explained on page 113, we found that the passage of an electric

current produced oxygen gas at the leading-in electrode, and hydrogen gas at the leading-out electrode. Having now accomplished this chemical change, by sending an electric current through the water, we take the battery away, and merely connect the two electrodes by a wire. As we desire, however, to know if any current now passes in this wire, we place a current detector, called a galvanometer, in the circuit, so that any current passing will move the indicator. As soon as we have the circuit completed, as shown in the lower photograph on opposite page, we observe from the galvanometer that a current is passing from the hydrogen electrode to the oxygen one, and this, we note, is in the opposite direction to that in which the current was passed during the decomposing operation.

It must not be supposed that we have stored electricity in the water-decomposing apparatus; we have merely stored chemical energy, which is again reacting and setting up an electric current. It is indeed as though we had just made an artificial or temporary primary battery. The electrical effect from this water-decomposing apparatus is of course very small, and would not really move the indicator of such a large galvanometer as I have used in the accompanying photograph. This must be taken merely as illustrative, the actual galvanometer used in such an experiment having too small a dial to show in a photograph, which will also include the tall decomposing apparatus.

Experiments were made, using various metals as the electrodes, in a bath of dilute sulphuric acid, and it was found that, when a current was passed through and the reaction tested, the effect was very much



1

2

WATER DECOMPOSED BY ELECTRICITY

1. The electric current from the battery is passed through the water. This causes the water to split up into its constituent gases, hydrogen and oxygen.

2. When the battery is removed and a delicate electrical instrument is connected in its place, there is found to be a reaction, causing an electric current to flow through the circuit. This current is opposite in direction to the battery current, and is only of short duration, but it is of importance.

(See page 113.)

greater with lead electrodes than with any other metal. These experiments, however, were made in 1859, a date prior to the invention of the practical dynamo, so that there did not then appear to be any large field for storage batteries made on this principle.

An accumulator or storage cell consists essentially of two large lead plates. These plates are not solid, in the modern cell, but are more like a framework holding in its meshes the lead which is to be affected by the current. This arrangement allows the electrolyte (dilute sulphuric acid) to have free access to the lead. This frame, support, grid, or backing serves both to hold the lead and to conduct the current, and must therefore be made either entirely or in part of metal, an alloy of lead being generally employed.

When an accumulator is connected to a dynamo, the chemical condition of the lead plates is altered. The plate by which the current is led in becomes darker in colour, being transformed into peroxide of lead, while the leading-out plate becomes a lighter grey colour as spongy lead is formed. The lead plates do not become efficient at the first charging, but are "formed" by repeated charging and discharging, which is, of course, done by the maker before putting the batteries on the market.

Accumulators may be made with large lead plates having great capacity, or they may be made up in small portable batteries. The current from these is a constant and steady one, so that they may be used as reservoirs in connection with electric light stations, in order to make an installation practically self-regulating. It is, of course, impossible to charge an accumulator from an alternating current, as each plate is alternately

the leading-in and the leading-out electrode. It is also necessary to use a continuous-current dynamo for electro-plating purposes, as otherwise the to-and-fro current would practically deposit the metal on one electrode and immediately afterwards carry it back to the other electrode, and so on.

The accumulator may be imagined to be analogous to a clock or watch. When a man winds up his watch, he expends a certain amount of energy in coiling up the spring, and it is arranged that this stored-up energy will gradually react, causing the spring to turn the wheels of the watch. One does not expect his watch to keep going on its own account; it daily requires a new store of energy. In the same fashion, a secondary battery will soon discharge, when it must be connected again to a dynamo and thus receive a fresh charge. When we pass an electric current through the accumulator, the chemical condition of the lead plates is altered thereby, and as these again work back to their normal condition they set up an electric current. This current is a reaction, and is therefore in the opposite direction to the charging current. This reaction only takes place while there is a connecting wire or path for the current to pass from the one plate to the other.

When we consider the vast electro-chemical industries described briefly in this chapter, and when we think of the ease with which the chemist of to-day may obtain the necessary electric current, it is interesting to read of the very great patience exhibited by an early experimenter, prior to the invention of the dynamo. The Hon. Henry Cavendish, a nephew of

the third Duke of Devonshire, devoted practically the whole of his life to science. Cavendish was desirous of combining the two chief constituents of the air, oxygen and nitrogen, by passing electric sparks through the gases. To do so he found it necessary that he and his assistant should, between them, keep his electrical machine constantly revolving for more than a fortnight. Imagine the persistent patience required, as the machine had to be turned by hand. Cavendish, who was a man of a peculiarly retiring nature, worked incessantly for the advance of science from the pure love of it, and we owe much to him in connection with the beginnings of electro-chemistry.

CHAPTER IX

ELECTRICITY FROM HEAT

Interesting discovery by a German professor—Vain hopes of a cheap means of generating electricity — Measuring temperatures to the one-millionth part of a degree—Recording the high temperatures of blast-furnaces, and the low temperature of liquid air—The true converse of electricity from heat

VERY long ago it was known that not only did friction produce electrification, but that some minerals when heated showed feeble signs of being electrified. The effect was indeed very small, and almost inappreciable. However, when Professor Seebeck, of Berlin, was experimenting in 1822 he made a very useful discovery. He was studying Volta's theory of the contact of dissimilar metals, and he found that when he heated the junction of two pieces of dissimilar metal there was quite an appreciable electric current set up through the metals if the circuit was completed.

The form in which this distinguished German professor first showed his discovery was by taking a block of the metal bismuth, and then bending a piece of flat copper plate into the form of an arch, so that one leg of the copper arch might rest on each end of the bismuth block. The metals were then soldered together at these two points. When heat was applied to one of these junctions, an electric

current was set up in this metallic circuit. This current could be tested by placing a small magnetic needle in the space between the bismuth and the arch, when the magnet would swing round, and take up a position at right angles to the electric conductor. Electricity produced in this manner was named thermo-electricity, to indicate its source.

When this source of electricity became known, experimenters tried the effect of different combinations of metals, which were found to give different degrees of electric pressure. The very best combination, which is bismuth and antimony, only gives an electric pressure equal to the one-hundredth part of that obtained from an ordinary battery cell. In an ordinary thermo-couple only one junction is soldered, leaving the other two ends free, to be connected by a wire at will. In order to increase the effect, a number of couples may be soldered together, and in this case one set of junctions, say all the odd numbers, are heated, while the others are kept cool. It is necessary to have a difference of temperature maintained between the two junctions. Even from large thermo-piles, built up in this fashion, the resulting current is very disappointing from a commercial point of view.

It was, for a time, a tempting problem to try to generate electricity on a commercial scale direct from heat, but it has been found quite impracticable. A thermo-pile has been made large enough to light up a small electric glow lamp of three candle-power, but the generator was exceedingly bulky for its capacity, and being heated by coal-gas, it was very expensive to maintain. Thermo-

piles have also been tried as batteries for telegraphs, &c., but they have no standing whatever in practice. It is possible with a pile of some thirty or forty couples to decompose water electrically, but the same may be much more easily accomplished by using a chemical battery of a few cells.

It is not even necessary to have two dissimilar metals to show a thermo-electric effect. If a steel bar, which has had one part of it hammered or rolled, and the other part annealed in a furnace, be subjected to heat, there is a small electric current effect indicated.

While we have no present hope of being able to apply thermo-piles for the purpose of generating electric current, there is a very important application of these thermo-electric currents. It is found that the small current generated by a thermo-pile is exceedingly sensitive to the slightest change of temperature in the source of heat. If one even touches the face of a thermo-pile with the finger, there is quite an energetic indication of an electric current shown by the delicate detecting apparatus. Thermo-piles have been made so sensitive that they detect a variation of temperature of less than one-millionth part of a degree. Electricity thus provides us with a thermometer far beyond the scope of any other form of thermometer for sensitiveness. For some purposes the thermo-pile may be a single pair or "couple." If two needles, of different metals, are soldered together at their points, they may be used by the investigator to probe animal or vegetable texture, and thus find the internal temperature.

Thermo-electricity does not confine its work to

the reading of very small differences of temperature. It also serves to indicate very high or very low conditions of heat. Who could hope by the aid of any ordinary form of thermometer to read the temperature of a blast-furnace? This may be done quite conveniently by means of a thermo-couple. In this case the couple must be made of two metals which will stand very high temperatures, and these are protected in a fire-proof porcelain tube. In one form of couple a wire of platinum is soldered to a wire of platinum rhodium, and from these there are two conducting wires passing up the long fireproof tube, and then away to the recording apparatus, which may be placed in the manager's office. This thermo-couple, when subjected to the high temperature of a blast-furnace, will generate an electric current, which will increase or decrease with the variations of the furnace heat.

The indicating apparatus may be a sensitive galvanometer. A simple galvanometer is a magnetic needle suspended in the neighbourhood of a coil of wire, the magnet being moved by the magnetic effect produced by any electric current passing in the coil. A much more sensitive instrument is one in which the magnet is stationary; and a very light coil, through which the current to be tested passes, is suspended between the poles of this stationary magnet. In this way we can use a large permanent steel magnet for the stationary one, and between its poles we suspend a very light coil of insulated wire, which also becomes a magnet as soon as any electric current passes through it, and will therefore be attracted round by the surrounding

poles of the stationary magnet. The greater the current passing through the coil, the greater will the turning movement be, so that it is only necessary to attach a light finger or indicator to the moving coil. This indicator will show the amount of difference of electric potential produced in the distant thermo-couple, but as this is varying with the variations of temperature in the source of heat, the movements of the indicator will therefore show the amount of such temperature variations. As the current produced is proportional to the amount of heat, we may mark off the dial of the indicating instrument in temperature degrees.

To sum up the matter, the heat of the furnace produces a difference of electric potential in the thermo-couple; this varies according to the temperature variations, and the electric current causes a coil and indicator to move in sympathy with the amount of current received, so that the indicator may be made to show the actual temperature of the furnace. If the stokers let the furnace temperature go down, the thermo-couple is less affected, the coil and indicator do not turn round so far, and a lower temperature is consequently indicated. Instead of merely having a moving indicator, the thermo-electric current may be caused to move a recording apparatus, so that a pen traces out the rise and fall of temperature, upon a paper carried past the pen point at a constant speed by clockwork. By a recording instrument of this kind, the manager can see exactly what temperatures the furnaces have been kept at, during the day or night. He may go home, locking up these recording instruments in his private office

overnight, and in the morning each will tell exactly how its furnace had been treated during his absence. Such instruments, whether recorders or merely indicators, are called pyrometers (Greek *pyros*, fire). Pyrometers are made to register as high as 3000 degrees Fahrenheit, and indeed the only limiting factor is the power of the thermo-couple to withstand a higher temperature. There is an instrument called an "optical pyrometer," which enables temperatures up to 7000 degrees Fahrenheit to be read, but this is only of use under certain conditions, as it requires that the light produced by the source of heat be visible.

Very low temperatures may be recorded by the electrical pyrometer, as just described. It only requires that the scale be suitably arranged, for if the couple be placed in a very cold temperature, there will be a difference of temperature maintained between its junction and the circuit, but this difference will, of course, be in the opposite direction to that produced when the exposed junction was heated. If we imagine the pyrometer standing a little above normal, and we then decrease the temperature, we can get it to read down to zero, and then continuing to decrease the temperature, the coil will continue to move round in the same direction. In this way we can read the temperature of liquid air, which is about 190 degrees Centigrade below zero.

When one sees liquid air for the first time, it is very difficult to realise that the liquid is really nothing but air ; perhaps the difficulty is increased when one sees it in the form of ice. It looks exactly like

ordinary water or ice. When a little liquid air is poured out upon the lecture table, and one sees it immediately vanish into air, its temperature being raised by coming in contact with the table, which is at a comparatively high temperature, then one finds it easier to realise that the liquid is air, and nothing but air, at a very low temperature. Commencing with air frozen solid, we increase the temperature, and we have liquid air, and still increasing the temperature, we have air in a gaseous form, which is its normal condition in nature. It is just analogous to ice, water, and water vapour, only that in the case of water, its normal condition on the earth is liquid. Any ordinary form of thermometer would be useless for obtaining an indication of these very low temperatures of liquid or frozen air. Mercury freezes solid when it has passed zero by about 39 degrees Centigrade. Spirits will record a lower temperature before solidifying, but cannot be used lower than 130 degrees below zero (Centigrade). These thermometers are also useless for very high temperatures, as mercury boils at 350 degrees Centigrade, while spirits boil long before mercury. We therefore see that electricity produced by heat is a most useful index to the temperatures of bodies which cannot be otherwise measured for temperature.

It may be remarked, in closing this chapter, that the true converse of a thermo-electric process is to pass an electric current through a thermo-couple, and in so doing it is found that the junction of the couple is heated when the current is sent through in one direction, while it is cooled if the current is sent through in the opposite direction. This heating

produced in the junction of dissimilar metals is quite a different effect from that produced by the passage of an electric current along any conductor. The latter effect must always be present, even when the current is cooling the junction, but with the small current used, the ordinary heating of the current is very inappreciable. However, in making calculations concerning the change of temperature produced in the junction, this ordinary heating effect has to be allowed for, but such small effects can only be satisfactorily handled by such men of science as Lord Kelvin. This heating and cooling effect in a thermo-couple when supplied with current, is called the "Peltier effect," after its discoverer, and the thermo-electric effect produced by heating the thermo-couple is often called the "Seebeck effect," after its discoverer. In both cases the effect is a very trivial one compared with the forces at work in an ordinary chemical battery.

CHAPTER X

ELECTRIC METEOROLOGY

The aurora borealis—An amusing incident—An artificial aurora —Photographing the aurora—Lightning—Franklin's experiment—An earlier experiment—Strange behaviour of a straw —The danger of playing with lightning—Fatal shock to a professor—Different forms of lightning—Remarkable display of ball-lightning—A "thunderbolt"—Analogy of smoke rings—The cause of thunder—Immense electric pressure in lightning

THE word meteorology must strike one at first as somewhat out of place in the sense in which it is now used. It might be translated literally as a discourse on meteors, or as the science relating to meteors. The word meteor was, however, originally used to signify all phenomena occurring in the skies, whether astronomical or merely atmospheric. In the present and the following chapter I shall include all electrical phenomena occurring in the atmosphere, although the word meteorology, as generally used to-day, refers merely to phenomena relating to the weather or climate.

Those who have seen the aurora borealis from any point in the extreme northern latitudes, have witnessed the most beautiful electrical display exhibited by nature. It is seldom seen to advantage in temperate climates, but is seen in all its beauty every night in the extreme north, while a corresponding display is seen in the far south, the latter being known as the

aurora australis. Those of us living in temperate zones have little idea of the real beauty of these auroræ. Indeed, the luminous effect seen here may be so feeble that it is apt to be mistaken for twilight, or for the ruddy glow of some imaginary fire at a distance.

During the siege of Paris in 1870, the first appearance of a very brilliant aurora was mistaken for the light from some great conflagration ; but when the luminous arch in the north-west horizon increased in brilliancy of colour, it soon became apparent that a very brilliant aurora was occurring. Bright streamers of pale red and pale orange tints crossed the ruddy glow, and these varied from time to time from pale rose to deep crimson. This same aurora was seen from Scotland, and in the country districts it was firmly believed to be the result of a large bonfire in which the Prussians were imagined to be destroying the besieged city of Paris.

In the far north the spectator sometimes sees the aurora in the form of golden draperies overhead, waving to and fro ; and these have seemed to be so close to the earth that some onlookers have said they felt as though they ought to be able to hear a rustling noise from the moving draperies. Indeed, it has been affirmed by some witnesses that they did hear a rustling noise. This may have been merely an imagination, or one might think of it as being due to an association of sensations ; but it is very probable that, if one was up in the air where the aurora is taking place, a hissing sound, such as accompanies a brush-like discharge from an electrical machine, might be heard.

There is an amusing story told of a Scotch professor who asked a student in his class what the aurora borealis was, and observing the student to hesitate, the professor told him to come along with his answer; whereupon the student said that he knew it, but had forgotten it at the moment. Turning to the class the learned professor said: "Gentlemen, this is most unfortunate; the only man who ever knew what the aurora borealis is has forgotten it."

While there still remains a certain amount of mystery in connection with this beautiful phenomenon, we have at least some idea of its nature, our real difficulty being to understand the source of the causes which give rise to this display. There is a great similarity between the appearance of the auroral displays and the luminous effects produced by electrical discharges in a vacuum, or more correctly speaking, in highly rarefied air. From a calculation of the height at which these auroræ occur, it is probable that the air at that distance above the earth is in a similarly rarefied condition to that which has been produced by the air-pump in the manufacture of the vacuum tubes referred to. These tubes, which are made of glass, have a short piece of wire entering the glass at both ends of the tube. As much air as possible has been withdrawn from the tube by means of an air-pump. If an electrical discharge from an induction coil or from an electrical machine be passed through one of these tubes, there will be a beautifully luminous effect produced in the tube. I shall postpone the explanation of an induction coil till a later chapter. The action which takes place in these vacuum tubes will be better

understood when we come to consider the science of the subject.

One point that may be mentioned now, as it has a definite bearing upon auroral displays, is that the luminous discharge in a vacuum tube is bent out of its straight course by a magnet brought near to it. Assuming, therefore, that the aurora borealis is an electrical discharge through the upper layers of the atmosphere, it is quite natural that these luminous discharges should be bent round to the magnetic poles of the earth. Then as the atmosphere bulges out, as it were, at the equator, owing to the rapid rotation of the earth, the height of the atmosphere is much less at the poles. The necessary degree of rarefaction of the air required to produce these luminous effects is therefore found to be much nearer the earth at the poles, than it is in lower latitudes nearer to the equator. We should, therefore, expect to see the discharge more easily at the poles, which, as is well known, is really the case.

We do not hear so much about the aurora australis, and indeed we do not possess the same amount of information regarding it, owing to the less frequent navigation in the Antarctic regions, and also because of the distance of land from the south pole. However, it is quite reasonable to assume that the electrical discharge takes place simultaneously at both poles. The auroræ of southern regions are not often seen from low latitudes, but they have sometimes been witnessed.

The bright light of the auroræ in northern regions is sometimes supposed to be of immense brilliancy, but one scientist, who has made many observations

in these far distant quarters, reports that at no time did he find the light from an aurora to exceed that of the full moon, and he could only with some difficulty read small print. However, one has to keep in mind that the whole surface of the earth in these regions is covered with snow, and from our own experience of moonlight on a snow-covered ground, we can well imagine how the brilliancy of the light is enhanced, so that the Lapps and Esquimaux may easily see their way about the snow-fields by the light of an aurora.

While we find records of "burning spears in the heavens," or of "appearances of lances in the sky," so far back as the sixth century, there seems to be little doubt that the auroral displays are now more frequent. The first scientific mention of aurora borealis was made in 1621, and many theories were advanced, but none of these proved adequate. When we can now produce in the laboratory luminous electrical discharges in rarefied air, and show that these bend round the pole of a magnet, there can remain little doubt as to the nature of this great atmospheric phenomenon.

During the sojourn of the Russo-Swedish expedition which went out to Spitzbergen in 1900, the auroræ were very carefully studied, more than a thousand displays being seen during one hundred and three days. In the first few days of December over two hundred auroræ were counted. As a rule the light was in constant motion, but quiet displays were photographed. One of the members of the expedition secured as many as seventy photographs, which are of scientific interest. The displays were described in a general

way as being made up of arcs, bands, and rays, with sharply defined edges of red or pink and indistinct borders of green. There does still remain a great deal of mystery as to the origin of the atmospheric electrification which gives rise to these phenomena, but this part of the subject will be dealt with in the succeeding chapter.

As regards the nature of lightning, there is left no doubt; it is an immense electric spark, caused by a sudden discharge of electricity. If we consider lightning to be analogous to a safety-valve for the escape of the accumulated electrification of the upper atmosphere, then we may look upon the aurora as a much better regulated safety-valve which permits the escape or discharge to take place slowly. In the former case we may imagine the accumulated charge suddenly let go with a bang, and in the latter case we see a gradual uniform leakage. We all know that if a metal conductor, terminating in a sharp point, is fastened to a high tower or taken aloft by a kite, we can "draw the lightning from the clouds." In a similar manner the discharge producing the aurora may be assisted by erecting a large surface of wires with projecting points. This has been done on some high mountains, and an electrical discharge has been obtained from the atmosphere, accompanied by a faint luminosity over the mountain while its neighbours were not affected.

When the illustrious American philosopher, Benjamin Franklin, suggested that lightning was an electrical discharge from thunder-clouds, it seemed a very bold assertion. Franklin wrote a paper upon

the subject some two and a half years before he made any of the experiments which he then suggested. This accounts for the fact that successful experiments were carried out in France before Franklin made his famous experiments in America. This could not have happened with any ordinary delay between the writing of the paper and the performance of the experiments, for there was no telegraphic cable to carry information, and all news had to travel by slow-sailing vessels. However, it was Franklin who suggested that an attempt should be made to conduct electricity away from the storm-clouds, by erecting a long rod or pole of iron on some high tower or steeple. A French philosopher, Dalibard, followed out this suggestion by erecting several such rods terminating in points, and insulated from the ground, and when a storm-cloud passed over one of these, the rod became electrified so that sparks could be drawn from its lower extremity. It was only a month later that Franklin, in America, performed a similar experiment, so that he could not then have received any word of Dalibard's successful experiment in France.

Franklin made his connection with the upper atmosphere by sending up a kite, instead of following out his first suggestion of erecting stationary rods. The wetted string of the kite was at first used as the conductor; but the following year another experimenter made a great improvement. He twisted a metallic wire with the string of the kite, thus offering the electricity a very much easier path from the kite to the earth end of the string. Holding the wire by a silken cord, which acted as an insulator,

this experimenter made many interesting electrical experiments. It must be clearly understood that these experimenters did not intend that their kites should act as lightning conductors, but merely as a means of tapping the thunder-clouds, and conducting away some of the accumulated electricity. The man who used the metal wire was able to conduct away more electricity than the man who used the wetted string of the kite.

One experiment carried out with the metal wire conductor was to fasten a tin tube to the end of the wire, suspending the tube about three feet from the ground. The experimenter then placed three straws of different lengths immediately underneath the suspended tube. In a little the three straws stood up erect and commenced a puppet dance under the tin tube, each straw keeping at a respectful distance from its neighbour. After watching these straws thus attracted by the electrified tube for some minutes, the experimenter, De Romas, and his friends, were greatly alarmed by a sudden discharge from the wire, accompanied by an explosion, after which there was observed a small hole in the ground immediately below the end of the tube, the hole being about one inch deep and half an inch wide. In Priestley's description of these experiments, given in his "History of Electricity," there is one very curious incident mentioned. He says that the most astonishing and diverting circumstance was produced, immediately after this explosion, by the longest straw following the string of the kite away up into the air. On its upward flight it was alternately attracted and repelled by the string, while a slight flash of light was visible

every time it was attracted. The straw was observed in its flight to a height of about one hundred yards.

It is quite clear that there was a certain amount of danger in playing with atmospheric electricity; but it is evident that in these experiments made by De Romas, the electrification of the clouds was not sufficient to produce a lightning discharge. One Russian professor, however, when making some similar experiments in St. Petersburg, received a fatal shock during a thunderstorm. This unfortunate experimenter, Professor Richmann, had arranged a vertical rod from the roof of his laboratory, and connected this to a metal ball on the ceiling of the room; but he had omitted to provide any possible way of escape for the electricity to earth, and on coming near to the metal ball, his body formed a conductor, so that the lightning discharged through his person.

It became clear that if a pointed conductor was placed on any high erection, such as a church steeple, and if the lower end of the conductor was connected to the earth, then the lightning could be conducted safely to the earth without any damage being done to the building. The electricity would not trouble to go through the stone building when such an easy path was offered it by the metal conductor. Previous to the erection of these lightning conductors, many superstitious country folk were in the habit of placing a leek on the roof of their houses during a thunderstorm; but how the innocent vegetable was supposed to act as a protection it is difficult to conjecture.

Lightning may occur either as a discharge between two clouds or from a cloud to the earth. It does

not often appear as a simple long spark or streak of light, but branches off in different directions from the main line, and all such discharges we commonly call zig-zag or fork lightning. What we know as summer or sheet lightning may be merely the reflection of one of these fork discharges occurring behind a cloud, or it may be that sometimes there is a diffused or partial discharge in the interior parts of the same cloud.

There is another class of lightning called globular or ball lightning; but this is much more rare, and is distinguished by its slow diffusion, its duration far exceeding that of ordinary lightning. There is no doubt that such forms of lightning are visible for at least ten seconds, and there are reports of much longer durations. In one case a man is said to have been sitting at a window on the first floor, and on seeing a large globe of fire moving along quite close to the street, he had time to come downstairs and watch it proceed some distance before it exploded. I have seen this very strange case recorded somewhere, but I cannot recollect the authority upon which the statement was made. However, we have a case quite as remarkable, which was reported by the great French experimentalist, Peltier. He tells us that while a large custom-house building was under construction in Paris, during the year 1839, a thunderstorm passed over the city, the clouds being so low that they almost touched the tops of the buildings. During this storm a "thunderbolt," in the form of a great ball of fire, fell into the open space in the centre of this unfinished building. Many of the workmen and clerks were sheltering around

this open space, and they saw the ball of fire fall and make a hole in the ground. Peltier says that it moved furiously about, throwing up the loose earth, then rebounding, it fell again a few yards distant, making another excavation, which was found afterwards to be only about half the size of the first hole. To the surprise of the onlookers, the ball of fire rebounded again from this second cavity on to the wall of the building, along which it moved for a hundred feet. The men noticed that the size of the fire-ball was considerably diminished; but it still had energy left to dash along the street over the wet pavement, and past the gates of the Hospital of St. Louis. By that time its mass had so diminished that it was only seen as a feeble light, which suddenly disappeared, evidently having expended its store of internal energy. Those who witnessed this remarkable display felt a smart electric shock, and all remarked upon the strong sulphurous odour which was left behind. One strange thing about this incident is that the ball of fire did not end its career in an explosion, which is the general order of things. I have conversed with people who have witnessed some very grand displays of ball lightning, and they all felt such occurrences to be awe-inspiring.

An erroneous idea got about that on such occasions there was a material thunderbolt lodged in the earth, this notion being the result of reports describing the holes actually made in the ground where the ball lightning fell. The ball of fire is undoubtedly material, but it cannot very well be composed of anything but air and gases derived from water-vapour. How this becomes so highly electrified is wrapped in mystery,

and must remain so until we have some more definite idea of the origin of atmospheric electricity.

It occurs to me that some readers may think it quite impossible that a ball of air and gas could act like a solid mass, but a few experiments with "smoke rings" help one to realise the rigidity of air when in rapid vortex motion. Smokers often amuse themselves by puffing out rings of smoke, which rise to quite a distance in the air. Similar rings on a much larger scale may often be seen issuing from the funnel of a steam locomotive. In experimental physics it is quite a common experiment to produce smoke rings by means of a box having a round hole in one side and a flexible back for the opposite side. If the box is filled with smoke and the back sharply knocked, a ring of smoke will be shot out from the box, and this ring will travel quite a long way. If the ring be rotating rapidly enough, it will rebound from any obstruction; or if the obstacle be very light, such as a feather, the ring will push the obstacle out of its way. Again, if two such rings come into collision with each other, so that their edges strike, they will rebound, and each will vibrate or stagger under the blow. The effect would be the very same if the rings were merely composed of air, but it is necessary to add the smoke in order to see the ring of air. If, however, the smoke be omitted, the air ring may be shot towards a lighted candle, at some distance away, and the light may be thus extinguished. Be it noted that an actual body of air moves from the one point to the other through the rest of the air. There are many other interesting experiments with vortex rings of air, but I merely mention these few facts here, as

they may help to remove a difficulty in connection with the behaviour of ball lightning.

There has been observed on rare occasions a "bead" form of lightning, in which the long flash appeared to be made up of little globes of fire forming a train. This bead lightning would seem to be an intermediate between fork and ball lightning.

When a long electric spark is drawn from a very large electrical machine, there is a considerable noise produced, like the report of a gun, and the same occurring on a much grander scale in the heavens, where the noise is echoed from one cloud to another, produces in our ears the effect of the thunder crash. The electric disturbance sets up air vibrations or sound waves. These travel through the air at a very slow speed, about 1100 feet per second, so that it takes the thunder some time to reach us. Light, however, travels through the ether at an immense speed, not falling much short of 200,000 miles per second. The light from the lightning therefore reaches us much quicker than the sound of the thunder. In this way we have a very simple method of calculating how far distant the lightning is from us. If we only desire an approximate figure, we may reckon the sound travelling at a speed of one mile in five seconds. If we count the seconds after seeing the flash, and find that there is a silence of fifteen seconds before the thunder is heard, then we know that the thunder has travelled a distance of three miles.

If after seeing a flash of lightning we fail to hear any thunder, it may be that the flash we saw was

merely a reflection of some far distant discharge, or it may be that the lightning we witnessed was at a greater distance than fifteen miles from where we were, for that is about the limit of the carrying power of thunder. We therefore see that there cannot be a great deal of energy in the thunder crash, for the report of a cannon will carry nearly four times this distance, while the noise of a bombardment will travel twice as far again. There is, however, an immense amount of energy in the lightning discharge, so much so that we often witness most alarming destruction of property and life. If we consider the electric pressure required to produce quite a tiny spark across an air space we shall then appreciate the energy in a lightning discharge. Remembering that a single chemical cell or "battery" only gives a pressure varying between one and two volts, we may be somewhat surprised to learn that a pressure of one thousand volts is required to cause electricity to jump across a tiny air-gap of the one-hundredth part of an inch. If the ends of two wires are touching each other when the current is started and they are then separated, the conditions are quite different, as a bridge is formed of gaseous particles torn off from the ends of the wires. At present we are considering two points with an air space between them at the outset. It is indeed remarkable that this small air space offers so great a resistance. If we now think of a lightning flash sparking across a distance of one mile, we may form some idea of the enormous electric pressure required.

CHAPTER XI

MORE ABOUT LIGHTNING, &c.

The effects of lightning—Remarkable damage to a church—A miraculous escape from death—Lightning protectors—Why an electrical discharge produces light—"Thunder clears the air"—An interesting experiment—Imitation of thunder-rain—Production of ozone—St. Elmo's fire—Curious experience on the Alps—How is the atmosphere electrified?—Armstrong's hydro-electric machine—Recording electrical changes in the atmosphere

If the lightning discharge actually strikes a building or a person, there should remain evidences of burning or charring, and any metal in the lightning's path should show some trace of fusion, but it often happens that no such effects are produced, and we may therefore presume that in such cases the lightning did not directly come in contact with the building damaged or the person injured.

While I was writing part of this manuscript, I saw a very ordinary flash of lightning, and at the same moment a telephone bell, quite close to me, gave a sharp ring. I do not suppose that the lightning actually struck my telephone line, for had it done so, the instrument was in such a position that I should doubtless have seen a spark across the lightning protector, but no doubt the neighbouring lightning induced or set up a sudden and momentary current on the line.

Photo by *Miss M. M. Metcalfe*

STRANGE RESULT OF LIGHTNING IN A CHURCH

There was very little damage done to the outside of the building. Indoors the marble steps were torn up and everything was in confusion, and some of the stonework of the window was injured, as may be seen; but there were no signs of burning, or of fusion of the metal articles, which are results one would expect to find.

A similar cause would appear to account for a strange incident which happened early in 1906, on which occasion a church was apparently struck by lightning, and yet there was no sign of burning or charring. During what my informant describes as "a queer little sudden storm," it was feared that Barsham Church, in Suffolk, had been struck. At the crash some members of the rector's family ran out to see what had happened, but as the tower was unhurt and the high trees round were not injured, they concluded nothing had happened and went home again, and it was not till the next day they found out what really had been done. My informant, who visited the church a few days later, writes: "We approached the church from the east end, and, knowing what to look for, saw that the east window had some of the tracery displaced and the gable injured and the glass broken in several places—I should have said in seven or eight, but I believe they say more than that; but they are little holes, and all in the white glass. Then we went inside, and considering that you could easily have passed the church without noticing the damage, it was perfectly startling to see the condition inside. The whole of the chancel was in perfect confusion. It looked as if a free fight had been going on. The altar cloth was all torn and tossed up as if the place was going to be swept. The marble steps had been torn up and hurled to a distance. The great candlesticks had been flung all over the place, and one of them was lying in the middle regularly rolled up in a piece of the frontal. I suppose it is a very fortunate thing that no one was inside, but it would

have been a curious thing to see the spirits of the storm playing such pranks." The accompanying photograph shows the interior of the church after the storm.

A friend tells me of another interesting case, and this will serve as an illustration of the usual heating effect produced by a stroke of lightning. "A draughtsman in one of the Tyne engineering works was going home for lunch during a thunderstorm accompanied by heavy rain. He was running, when he was struck by lightning and rendered unconscious. It was found that the metal wire in the rim of his felt hat was fused, the hat being torn to rags. All the pieces of metal about his person and in his pockets gave evidence of fusion at the loose contacts, the coins in his pockets being fused together, and the lid of his watch being fused to the case. He wore long woollen stockings, one of which was burnt from top to bottom. The boot, which was on the ground, was burnt, and the nails in the sole had every appearance of having been red-hot and having burned the leather. He remained unconscious for several days, but quickly recovered, and was back at his duties within a few weeks, none the worse for his extraordinary experience. He has no recollection whatever of the incident, but remembers leaving the office for home and running through the rain."

The effect produced by the lightning in this case is quite different from that in the case of Barsham Church, for in the latter there was no sign of fusion of the metal articles disturbed by the storm. In the case of the Tyne draughtsman, I have no doubt that

his wet clothes were his salvation. Lightning is at such an immense electric pressure that a very small conductor, such as the wet clothes, might conduct most of the charge to earth.

In constructing lightning conductors it is advisable to give the high-tension discharge a clear path and a good connection with the earth by means of a large metal plate sunk in the sub-soil. The water-mains may also be connected, but if we fail to give the electricity a clear path, it may leave the conductor and do much damage to the property which we are seeking to protect. It has been pointed out that the only sure lightning-conductor is to cover the building with a wire gauze. It is not convenient to put an ordinary building into a metallic cage, but it is wise to adopt such precautions in the case of powder magazines or stores of highly inflammable materials.

Lightning protectors have been mentioned already in connection with tramway cars in chapter iii. It will be remembered that an earth wire is provided, but that this cannot be directly connected to the wiring of the car, or the current from the generating station would take a short cut to earth by it. It is sufficient, however, to have the earth wire placed near the conducting wire, leaving only a small air-gap between. It is impossible for the current from the generating station to leap across this air-space resistance, but if lightning strikes the conducting wire it has no difficulty whatever in crossing this space and getting to earth. It was pointed out in this connection that if the lightning once crossed the air space, it formed a bridge of gaseous vapour, by

means of which the current from the generating station could then cross. It is therefore necessary in protecting such conducting wires to make the lightning protector, when "struck," automatically increase the air space and thus prevent the current from the generating station continuing to run to waste. Such automatic devices are, however, only necessary where the conducting wire is carrying a current at a comparatively high pressure, such as is used for electric traction. A simple fixed air-gap is quite sufficient in connection with telegraph and telephone circuits, where only a very small electric pressure is used. In the case of expensive submarine telegraph cables great care must be taken in providing an efficient lightning protector for the land wire, for if lightning were to strike this wire and reach the submarine cable it might rip up the insulating cover and leave the cable useless.

There is considerable mystery regarding the cause of the spark or flash of light produced by an electrical discharge. Why should there be any light? Of course a slow and very gradual discharge, which we should term a leakage, is not accompanied by any light. It may be that an energetic discharge in air, however, causes such a sudden displacement of the air particles that we may imagine them being thrown with great violence against the surrounding stationary air. The speed of these moving particles is so great that the surrounding mass of air acts like a dead wall. This sudden bombardment produces an intense heat, which in turn gives rise to the luminosity. It is interesting to note in this connection that if we

take a "vacuum" tube, already mentioned in connection with the aurora borealis, and if we cause an energetic bombardment of the air particles in the so-called vacuum, it is possible to raise a piece of metal to a red heat by placing it in the path of these moving particles. This will be better understood, however, when we come to consider what these luminous rays are.

There is another phenomenon connected with thunderstorms which no doubt we have all observed since childhood. It is perhaps most graphically described by the expression, "Thunder clears the air." Especially noticeable is this in summer time, when previous to a thunderstorm we have felt a heavy drowsiness as though the air had lost its vital force, and on going out of doors after the storm has passed we find the atmospheric condition entirely altered, and there is then quite an exhilarating effect. What has happened is that before the storm the air had probably been very still for some days and its oxygen had been somewhat altered in condition, so that our lungs failed to receive the usual stimulus, but when the electric discharge, in the form of lightning, passed through the atmosphere the oxygen was again energised and our sensitive lungs at once appreciated the change. This has been practically demonstrated in the laboratory. Some animals were placed in a glass chamber containing pure oxygen, whereupon they showed signs of exhilaration, but the effect soon passed off and they became drowsy. The gas was then drawn off and the remaining oxygen was purified, and when tested could not be distinguished from freshly made oxygen. When this gas was again

given to the animals they still showed signs of drowsiness. Then a most interesting discovery was made. It was found that if an electric discharge was passed through the oxygen gas the animals at once threw off their drowsiness, and they found the oxygen as exhilarating as at the outset.

It has been suggested that in the still days preceding a summer thunderstorm the oxygen of the air has been robbed of its energy by passing through the lungs of warm-blooded animals, and while this no doubt does take place, it seems to me as though there must also be some larger influence at work to cause this result in so great a volume of air.

Another benefit which doubtless arises from an electrical discharge, such as lightning, through the atmosphere, is that the fine dust in the air will be deposited upon the ground. This is amply proved in the laboratory, and is indeed applied on a large scale in depositing the poisonous fumes in lead factories, &c. It has also been suggested as a means of clearing the atmosphere of fog.

It is also interesting to note that the large drops of rain accompanying a thunderstorm may be imitated in the laboratory. It has long been known that if a fine jet of water be forced up into the air so that the water falls in a fine spray or mist, and if a piece of electrified sealing-wax be then brought near to the water issuing from the fountain nozzle, the spray immediately forms into large drops, so that what seemed before to be merely a mist then becomes a shower of water. It is certainly very remarkable that such a small electrical force as may be obtained by rubbing a piece of

sealing-wax on one's coat-sleeve should produce so large a result.

There is another effect produced in the air by an electrical discharge, and any one who has been close to a large electrical machine at work must have noticed it. There is an odour produced, rather suggestive of sulphur, and this same brimstone smell which accompanies lightning at close quarters was no doubt quite sufficient to convince the superstitious that lightning was a work of the devil. This odorous gas was long ago named ozone, but it is now believed to be oxygen in an altered condition, and indeed may have some bearing upon the energising of oxygen already mentioned in connection with thunderstorms. This ozone is now produced artificially, and is used as a disinfectant, but this subject will fall more naturally under the title of "Medical Applications" in chapter xxi.

There is a phenomenon known as St. Elmo's Fire, which occurs more often at sea, and may be described as luminous electrical discharges slowly escaping from points such as the masthead of a ship. These occur when the atmosphere is said to be rich in electricity, and are usually looked upon as good omens by sailors. No damage arises from such displays. The same phenomenon sometimes occurs on land, and one of the most interesting cases I have heard of was the experience of an Alpine party, some of the members of which were Fellows of the Royal Society (London). While crossing a glacier during a thunderstorm these gentlemen were surprised to hear a sound, like the singing of a kettle, issuing from the ends of their alpenstocks. At the same time they experienced

prickly sensations on the tops of their heads, and observed other signs of electrification.

There is no doubt some intimate connection between atmospheric electricity and the phenomena known as whirlwinds, waterspouts, tornadoes, &c., and probably also the production of hail-stones, but until we gain some clearer knowledge of the cause of atmospheric electricity, none of these phenomena can be properly understood.

It is a very natural question to ask, How does the atmosphere become electrified? It has been suggested that the electrification is produced by friction between the air and the ground, but this does not appeal to one as a satisfactory solution. Another suggestion has been made that it is due to the evaporation of water ascending into the atmosphere, but very exhaustive experiments have failed to detect any electrification due to simple evaporation. It has been clearly demonstrated, however, that the friction of particles of water against material substances is well able to give rise to strong electrification. This was first observed by an engineman as far back as 1840, and was investigated by the late Lord Armstrong. The engineman found that when he touched the steam boiler, which was under his care, he received quite a startling electric shock. I may remark in passing that I have found this engineman's name given as Seghill, but from a letter written by Armstrong to Faraday, and published in 1840, it is clear that Seghill was the name of the place at which the discovery was made and not the man's name. Armstrong found that the electrification was due to some escaping steam; the boiler being on bricks prevented the electric charge

from escaping to earth. Armstrong afterwards constructed a hydro-electric machine, which consisted of an insulated steam boiler, from the safety valve of which jets of steam were thrown against sharp metal points which became electrified.

An American professor relates a curious case of electrification coming within his own experience. The telephone operators dealing with a particular circuit complained of electric sparks occurring on their lines. Upon investigation it was found that a steam locomotive was at such times standing on a siding directly under the overhead wires of this circuit. The steam, or more correctly speaking the water particles, escaping from the safety valve of the boiler, impinged against these overhead wires and electrified them to such an extent that sparks were visible in the telephone exchange. It is very remarkable that so great an electrical disturbance should result from such a simple cause.

Again, it has been found that the friction of dust particles in a sandstorm is a cause of electrification, for the tops of the great pyramids have been found to be appreciably electrified after the passage of a sandstorm.

There seems to be room for research work in connection with the cause of atmospheric electricity, for it is reasonable to presume that the electrical condition of the atmosphere must have a distinct bearing upon the other changes constantly taking place. It may be that some day, when a better knowledge of atmospheric electricity has been obtained, one may come to place implicit confidence in the forecasts of our friends the meteorologists.

Of course there must always be the difficulty arising from the fact that quite a variety of conditions of weather may occur simultaneously in places not very distant from one another. It may not be too wild a dream to imagine that when electricity can be generated for "next to nothing," local districts may employ electrical means to draw rain, or ward it off, as desired.

The changes of electrical condition in the atmosphere may be recorded by placing an insulated copper vessel in the air and allowing water to drop constantly from it. The metal vessel becomes electrified in sympathy with the surrounding air. This charge is then led into the observatory where its attractive power is compared with that of some standard of electric pressure.

Having had an opportunity of watching the records produced by such instruments as just described, I feel persuaded that merely studying the changes at one fixed level is of little use. One would require to learn the electrical changes at various heights in the atmosphere simultaneously.

Suggestions have been made to tap the electrical resources of the atmosphere, which at its upper layers has a considerable pressure, but for the present this does not seem a practical problem. Another suggestion has been to draw upon the silent earth currents which so often disturb our telegraph circuits, but this too can only be a dream as yet.

There can be little doubt that high charges of electricity exist far beyond our atmosphere, but connected with the sun and other celestial bodies. It seems very probable that the beautiful streamers of

the corona, seen during a total eclipse of the sun, may be due to electric discharges. I recently saw a very beautiful imitation of the corona produced on a laboratory scale by causing a high tension discharge between two wire rings, one ring being hidden by a disc of black paper.

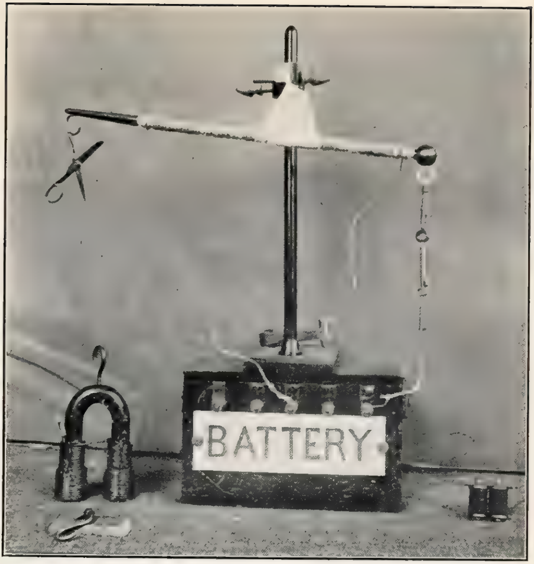
CHAPTER XII

LIGHTER DUTIES OF ELECTRICITY

How electric bells work—Electric indicators and burglar alarms—The future of automatic fire-alarms—An electric clock without a battery—A lunatic's joke—Some clever mechanisms—How electricity aids the railway signalman—Electricity and sea-sickness—Safety devices in mines—Prevention of "racing" in marine engines—The felling of trees—Electricity's aid to the farmer

In the preceding chapters we have seen electricity performing very arduous duties, propelling trains and tramway cars, driving the machinery in factories, producing light for great cities, heating immensely powerful furnaces, or in another sphere decomposing millions of tons of matter. In the present chapter we shall see that electricity will also aid us in what might seem trivial matters as compared with these large calls upon its power.

The most conspicuous of these lighter duties is the electric bell; we press a button, and electricity does the rest, and will even indicate to an hotel porter from which of several hundreds of rooms the signal was sent to the one common bell. The mechanism of the bell is very simple, consisting of an electro-magnet which when energised by the current will attract a gong-stick, causing it to strike upon a gong. The simplest form is the single-stroke bell, which will strike the gong each time the distant push is pressed.



I

2

1. A kitchen poker made to lift keys and scissors, and to let them go at will.

2. An electro-magnet, at the Royal Arsenal, Woolwich, lifting a heavy projectile. The second projectile is merely slung on with ropes to show that the small magnet can carry a

The pressing of the push allows the current from a battery to pass through the wires of the electro-magnet. Such a bell is very useful for signalling on tramway cars, &c. &c., but is not energetic enough to call the attention of a servant who happens to be at some distance from the bell. If the push was rapidly pressed and let go alternately the bell would give a number of strokes in quick succession, but it is not necessary that the person operating the push should be at this trouble, for the bell may be arranged so that as long as the push is kept closed it will continue to ring. It is evident that the bell itself must then do the making and breaking of the circuit, so that the current may get to the bell, then be stopped, get to the bell again, and so on, thus causing the gong-stick to be attracted, let go, attracted again, and so on.

Bells of this class are descriptively named trembler bells, and are by far the most common form in use. The only difference between these and single-stroke bells being that they must of themselves break the circuit at each stroke. If we pressed the push for the single-stroke bell, and kept the push closed, the current would continue to pass around the magnet, and the gong-stick would therefore remain in contact with the gong till the push was released, when it would be pulled back by a spring. In the trembler bell it is arranged that when the gong-stick advances to strike the gong it breaks the circuit through which the current is reaching the electro-magnet, so that the magnet lets the gong-stick go, and in falling back again into its normal position it again closes the circuit, causing the magnet to again attract the gong-stick. In this way the making and the breaking of

the circuit is accomplished by the bell itself, saving any one the trouble of doing the making and breaking of the circuit at the push. The mechanical arrangement is very simple. When the gong-stick is at rest its spring holds it against a little upright pillar, and the current passes up this pillar, whenever the push is closed, but in order to get to the electro-magnet the current has to pass through the gong-stick. It does so, and then its path is immediately broken, for the gong-stick has been attracted forward and is no longer in contact with the upright pillar which was feeding on the current. The sudden attraction, however, has caused the gong-stick to strike the gong, and the electro-magnet having lost its attractive power, the gong-stick springs back against the pillar again, and if the push is still closed, this to and fro motion will be continuously kept up. It is this rapid to and fro motion, or trembling, of the gong-stick between the pillar and the electro-magnet which gives to it the descriptive name of a trembler bell.

Any number of different wire circuits may be run out from one of these electric bells, so that it may be rung from a great many different points. Each circuit is, of course, broken at some convenient point and a push inserted in the circuit. In order to show from which room the bell has been rung, it is necessary to have the wires leading from each room connected to a separate small electro-magnet in an indicator board, placed beside the bell. When any push is now closed the current must pass around the particular magnet in that circuit on its way to the bell. It only remains now to arrange that this little electro-magnet will move an indicator. A small shutter

may be caused to drop and expose the number of the room to which the electro-magnet is connected, or a small pendulum may be set in motion causing a brightly coloured disc to swing to and fro in a space allotted to it, each space being marked with the number of a room. Many different forms of indicators or annunciators are in use, but the general principle is the same.

It will be readily understood that electric bells may be arranged as burglar alarms, the circuit being closed by the opening of a door or window. Electricity may also be made to ring a bell when the temperature of a greenhouse, or of any heating vessel, rises to a certain point. A very simple plan is to fix the end of one wire from the bell into the bulb of a mercury thermometer, and fixing the other wire into the glass tube, opposite any desired degree on the scale. When the mercury is below this point in the tube the bell will remain silent, but as soon as the mercury reaches the end of the wire in the tube the electricity can get from the lower wire in the bulb to this other wire, the current passing through the liquid metal mercury. Thus an alarm may be given to call the attention of a gardener to the fact that his greenhouse is being overheated, or the thermometer may be used for any other similar purpose.

A most useful application in this sphere is an automatic fire-alarm, but as its chief value will lie in its being able to give the alarm at the earliest possible moment, it must be a much more sensitive instrument than an ordinary mercury thermometer. It must act immediately upon a sudden rise of temperature, and yet must pay no attention to a gradual increase.

Leaving the question of automatic alarms out of account for the present, one would expect that in a crowded city or town the citizens would be wide awake to the importance of providing means of signalling immediately to their fire-station that a fire had broken out in a particular quarter. We therefore find most towns well provided with fire-alarms in the streets, so that any person can break the small glass panel of the instrument and press the push, thus giving the alarm to the fire-station. In some forms of alarm there is a "pull" lever instead of a push. When the push is pressed it remains in, and cannot be released till the fire-alarm case is opened. There is a large trembler bell in the street fire-alarm case, which commences to ring whenever the push is pressed in, and at every to and fro stroke of its gong-stick it sends an electric current to the alarm bell in the fire-station. This bell in the fire-station is a single-stroke one, and the advantage in this is that should any other current get on to the overhead line wire leading to the fire-station, through some other conducting wire coming in contact with it, then this bell will only give a single stroke on its gong, or at the most a number of separate strokes quite detached from each other. On the other hand, when the current is coming in at each stroke of the outside trembler bell, then the single-stroke bell will make rapid to and fro strokes and will exactly imitate the trembler bell. This arrangement, which is the principle instituted in Glasgow, is of great importance, as any accidental short circuiting of the overhead line wire cannot be mistaken for alarm of fire.

At the fire-station there is a separate fire-alarm bell

representing each street alarm, and each of these receiving bells has an indicator shutter which falls and exposes a red disc when its bell rings. As long as the street bell continues ringing so will the fire-station bell also ring. It will never do to let these two bells ring incessantly till the firemen reach the distant street alarm, and there release the push. This is not necessary, as each bell in the fire-station has a little lever or key attached, and whenever the call has been noted by the fireman on duty, he pulls down this lever, which breaks the circuit for both bells. The person who operated the street alarm then knows that the signal has been received at the fire-station, by his local bell ceasing to ring. When this little lever at the fire-station is depressed to its full extent it connects the incoming line wire to a telephone instrument, and as soon as the firemen reach the street alarm from which the call was given, one of the men connects a portable telephone to the street alarm and reports to the fire-station what further assistance is required, and the nature of the fire, &c. Constant communication is kept up in this way with the fire-station as long as the brigade is out.

While resident some years ago in a town of seventy or eighty thousand inhabitants, I was surprised to find that the town did not possess a single fire-alarm. If a citizen should observe a building on fire, there might happen to be no telephone in the immediate neighbourhood, places of business being closed at night and there being very few private telephones in this town. Then the person observing the fire must needs run on foot a distance of possibly two miles in order to give the alarm to the fire-brigade. On one

occasion when the delay resulted in a child being burned to death, I took the opportunity of calling the attention of the townspeople to the antiquated system upon which they worked, and the editor of the local newspaper backed up this appeal for a supply of fire-alarms. That was thirteen years ago ; but as six years after this appeal had been made there had been no action taken in the matter, I again took a suitable opportunity of bringing the matter before the citizens, pointing out that their existing method was analogous to a cat playing with a live mouse before attempting to kill it. It looked as though there was a desire that the fire should first have a good hold of the building before any attempt was made to extinguish it. Even now I understand that the busy manufacturing centre, to which I refer, still refuses to supply its inhabitants with these most necessary street fire-alarms.

As already indicated, electricity enables us to dispense with the human agency. An automatic fire-alarm will keep watch in a building locked up for the night, and will signal immediately to the fire-brigade or to any desired point. There are many different forms of automatic fire-alarms, but all have one general principle. The sudden heat from an outbreak of fire causes an electrical contact to be made, and thus a signal is sent direct to the fire-station. It is just as though we arranged that the automatic fire-alarm would press a bell-push on the outbreak of fire. In one form of alarm a piece of flat metal spring has a small push resting on it, and the sudden rise of temperature causes this metal spring to expand and press the push upwards, closing an electric circuit, and thus giving the alarm.

Another very sensitive form of alarm employs two metal vanes or gutters which are placed on edge and bent in towards each other at their centres. The length of these will be about 18 inches. The vanes are fixed to a metal base, being electrically insulated from the base. As their ends are fixed, any expansion of the vanes will cause them to bend still closer together at their centres. In doing so they cause two multiplying levers to be moved, and the ends of these make electrical contact, and complete the battery circuit of an alarm bell, which may, of course, be placed at any distance. The metal vanes are so sensitive to any sudden rise of temperature that they expand sufficiently in a few seconds to give an immediate alarm on the outbreak of fire. Any gradual increase of temperature causes the whole instrument to expand equally, so that the metal base expanding at the same time as the vanes, which are fixed to it, there is no further bending of the vanes, and therefore no alarm is given. It is only in the case of the sudden rise of temperature, consequent upon the outbreak of fire, that the vanes expand before the heavier base has time to do so, and therefore bend inwards, producing a movement which when magnified by the multiplying levers is quite adequate to complete an electric circuit.

One system of automatic fire-alarms sends signals to the nearest fire-station. A Morse-inker telegraph instrument in the fire-station receives the signals from all the different alarms. When the automatic alarm completes a local electric circuit it releases a clockwork contact-maker, which is arranged to send a certain combination of signals.

One alarm may send a dot, a dash, and a dot, and as it will continue to repeat this signal for some time there can be no mistaking it when it appears upon the paper ribbon of the Morse-inker in the fire-station. The fireman in charge of the room in which fire-calls are received has a code beside him informing him of the buildings denoted by the different arrangements of Morse signals.

Another of the lighter duties of electricity is to save us a great deal of trouble and expense in maintaining a legion of separate pieces of mechanism to indicate the time of day. Does it not seem remarkable that in almost every room of a large house there should be an individual clock which must be wound up and regulated? We have tens of thousands of separate pieces of mechanism in a large town, all seeking to do the very same thing, all endeavouring to keep in step with Greenwich time. Instead of all these we may have one standard clock for every district, and it will be a simple matter to ensure this one clock keeping good time. All we now want are simple clock-dials which will move the hands forward one step at every minute, or half minute, upon their receiving an electric impulse from this master clock. This controlling clock may close an electric circuit at the end of each half minute or minute, and the current reaching an electro-magnet in the distant dial attracts a lever which in turn moves the minute hand forward one step.

In most electric clock systems the power is got from batteries, and the master clock closes and opens the circuit. There is one very ingenious

system which dispenses with batteries altogether, and also does away with the necessity of making and breaking the circuit. This would at first sight seem to be too good to be true. Where is the necessary energy to come from? If one looks at the master clock it is evident that a very heavy weight is going to supply the power. The weight is heavier than is required to drive an ordinary clock, for the master clock has to do more than drive itself. It will be remembered that the great Faraday discovered that if a coil of wire was quickly moved in a magnetic field, there would be a current of electricity generated in the coil of wire. We have seen how the dynamo was evolved from that simple discovery. The master clock repeats Faraday's simple experiment. At the end of each minute it moves a coil of wire quickly across a magnetic field produced by a large permanent magnet. This moving coil is part of the circuit in which the distant dials are placed. That is to say, the wires leading from the dials are connected to this coil in the master clock. When an electric current is generated in the coil, the current, of course, passes round the whole circuit, thus operating the electro-magnet in each dial.

It is claimed that the momentary current generated by these master clocks will travel through fifty miles of wire and operate five hundred clock-dials if necessary. Surely it is a great advantage even to have one master clock for a large building and electric dials at every convenient point. These systems are necessarily making slow but sure progress, but when they come into quite general use, we need not offend a friend by asking if his clock

is about right. Nor shall we have to remember to wind up or regulate our clocks. In these days a clock that is not always right will not be tolerated. I know of an amusing case which occurred recently. An inmate of a lunatic asylum pointed to an ordinary clock in the establishment, and asked the doctor, "Is that clock right?" When the doctor replied that it was quite right, his patient said, "What is it doing in here then?" Till some electric system of clocks is firmly established we must not be surprised to learn that a friend's clock is "about five minutes slow," for we do not at present count that even this want of rightness necessitates its confinement in an asylum.

Electricity assists in a great many different branches of life. For instance, it enables the astronomer to record the exact time of the occurrence of any phenomenon to the five-thousandth part of a second. An instrument for this purpose is called a chronograph, and may be put to many other uses. It enables us to tell at what speed a projectile is travelling, for we may cause the projectile in its flight to make an electrical contact in passing each of two or more points at fixed distances apart. As each electrical contact is made the chronograph records the exact fraction of a second at which the circuit was closed. By such means it is even possible to tell at what speed a projectile is travelling along the bore of a gun.

Electricity also provides us with very ingenious little machines by means of which we may keep a continuous record of the velocity and the direction of the wind. There are many other recording in-

struments of this class dependent upon electricity, but as I have already dealt with this special subject at some length in "The Romance of Modern Electricity," I shall not go into any details here. The same remark applies to the application of electricity to conjuring, &c.

The subject of railway signalling naturally falls within the scope of this chapter, but as the chapter on telegraphy succeeds this one, I shall leave over that part relating to the "Block system" and deal with it then.

Electricity assists the signalman in many other ways. If any of his outdoor semaphore signals are out of sight, he has a small model in the cabin before him, and when he lowers or raises the distant semaphore, he sees from this model whether or not the signal has worked properly. The little semaphore arm in the model is moved electrically by a contact on the distant signal-post, so that whatever position the model semaphore is in, the signalman knows his outdoor signal is in the same position. Electricity may also signal to him if any night light on a signal-post happens to go out. In some large railway stations the signalmen now operate the outdoor signals by electricity, while in some cases electric motors supply the energy for moving the points, &c. Then on many railways there are safety devices, so that the road must be set clear for an approaching train before it is possible to lower the semaphore signal, and thus allow the train to pass. Another arrangement provides that when a train passes No. 1 signal an electrical contact made by the last coach

causes the signal to automatically set to danger. This signal cannot now be lowered till the train has passed No. 2 signal-post, in passing which a similar electrical contact is made.

Purely automatic systems have been devised, dispensing with human control. Signals may even be given, to the driver, directly on the engine itself, as is done at Woodhead Tunnel, on the Great Central Railway (U.S.A.). All such automatic devices, while of use on a length of simple track, are quite out of question wherever a junction is concerned. If one keeps a look-out, say in travelling from London to Edinburgh or Glasgow, a run of over four hundred miles, it is surprising how very little of the whole road is free from junctions. In America there are, of course, much longer stretches.

One very odd application of electricity is to provide an armchair or couch for the prevention of seasickness. The chair receives a vibratory movement from an electric-motor and an eccentric, and it is claimed that the occupant is immune from *mal de mer* as long as he or she is seated in this chair. As the chair has an up and down motion, it is clear that the occupant will be alternately moving with the ship and then in the opposite direction, and those who have tried such chairs on some of the large ocean steamers say that they were quite free from sickness while sitting in one of them, at such times as they could have no other hope of keeping free from this trouble.

With the introduction of the Davy safety lamp,

and its followers, into coal mines, there was a most marked decrease in the number of disastrous explosions. So much has this been the case that we have come to consider the falling of small portions of the roof, burying perhaps only one miner at a time, to be a greater source of danger. Sometimes, however, we are still horrified to learn of most disastrous explosions and fires, such as the Courrieres Mine disaster in 1906, by which over one thousand lives were lost. Then, closely following that catastrophe was a similar case in Japan, in which several hundreds of miners perished. It is therefore of the very highest importance that all possible safety devices should be used. Portable electric lamps have not found much favour in mines as yet, but the ordinary miner's lamp may be lighted electrically without opening the lamp. Magnetic locks have also been applied to lamps, so that it is quite impossible for any miner to open his lamp. The locks can only be opened by a powerful electro-magnet kept upon the surface.

When a steamer is driving across the ocean in bad weather there is a considerable strain put upon her. Every time the vessel pitches forward and tilts up her stern, causing the propellers to be lifted partially or wholly out of the water, the engines tend to "race." The resistance of the water being suddenly withdrawn causes the propellers to fly round at a great speed, and another strain arises when they again touch the water. In order to save the engines as far as possible, an engineer is sometimes stationed at the throttle valve, ready to shut off the steam every

time the propellers rise out of the water. Unless he is able to anticipate to a certain extent the rise of the stern, it is quite impossible to prevent some racing. Electricity has been called in to act as the controller, and has proved a faithful servant. There is an open pipe or "sea-cock" placed at the stern of the steamer, the position of the inlet being such that it is under the water as long as the propellers are in the water. The water entering the sea-cock keeps a certain pressure on the piston of a small cylinder, placed near the stern. When the water pressure is relieved by the stern rising up out of the water, the piston descends, and in doing so it makes an electrical contact. This part of the mechanism is analogous to having a look-out at the stern, whose duty it would be to press an electric push each time the stern commenced to leave the water. The mechanical arrangement in a case of this kind is, of course, far superior to any human look-out.

When the electric circuit is closed, an electric current passes through a coil of wire or solenoid in the engine room. This coil thus becoming an electro-magnet attracts a metal core which operates the valve of a small cylinder, and the piston of this cylinder closes the throttle valve of the large engines. When the stern of the steamer again descends, the water pressure forces up the piston in the small anticipating cylinder acting as the look-out at the stern. The electric circuit is again broken and the engine valves once more automatically opened. It is claimed for this anticipating governor that it far outstrips all other governors which are purely mechanical, the reason of its

advantage being that electricity does away with any mechanical connection between the controlling or observing part at the stern, the electric current conveying the necessary energy to shut off the steam valves, in "less than no time."

Among the manifold applications of electricity may be mentioned the felling of trees. In some of the forests of France the axe and the saw are no longer used. They are replaced by a simple platinum wire, which, when made red hot by the passage of an electric current, and then used as a saw, cuts or burns its way through the trunk of the tree in far less time than any saw could do. This novel method has two advantages; it makes no sawdust, and the slight carbonisation, due to the burning, helps to preserve the wood at the point of severance.

While the agriculturist finds electricity a very convenient motive power, to aid him in the tilling of the ground, the cutting down of the grain, &c., he may yet claim its services in another direction beneath the soil. Electricity applied to seeds facilitates their germination. The electric current decomposes the natural salts of the earth, thus making them more easily assimilated by seeds or plants. It has been amply proved that by electrifying seeds their growth is very materially hastened; barley having been thus germinated in two days in place of five. From experiments carefully carried out it has been shown that by electrifying plants at night the current produced the same effect on the plants as does the light of the sun. There is no doubt that electricity

increases vitality and assists the "breathing" of the plant, favouring the exchange of gases between the foliage and the atmosphere. At present the subject is in an experimental state, and we must leave it to the horticulturist to decide whether the electrified plant is superior or inferior to the plant grown under natural conditions.

The lighter duties of electricity are almost without number, but sufficient detail has been given to show the very varied character of its applications.

By permission of *Siemens Brothers & Co., Ltd.*

A HANDY ELECTRIC TOOL

The workman has merely to hold the tool in position and electricity supplies the energy required to drill through the iron casting.

(See page 74.)

CHAPTER XIII

TELEGRAPHY BY LAND

An early attempt at telegraphy—Intelligence by signals—The Morse sounder and inker—How high speed is attained—Some clever inventions — A number of operators send different messages over one line at the same time — A telegraph repeater—Distribution of important news—How Morse came to think of his telegraph—An English invention which has had to give way to the American—The needle telegraph in railway signal cabins—The Block system—Some other ideas—The meaning of an earth circuit—An ingenious printing telegraph—An unsolved problem

It was said of an early experimenter that he could "make lightning speak and write"; this picturesque description of telegraphy was more real in those days than at the present time. The man of whom this extraordinary statement was made was one Charles Morrison, who practised as a surgeon in a small Scottish village. He sent messages by electricity from one cottage to another in the village of Renfrew, about the middle of the eighteenth century, when the only form in which electricity was known was the electrical charges produced by glass plate machines, or by what has been termed "frictional electricity." The electrical discharge from such machines is indeed lightning on a small scale. It is interesting to note that, in the same village of Renfrew, the largest electrical machine of this class

ever made, was constructed by Lord Blythswood in his private laboratory there some years ago.

Morrison and all other inventors working on similar lines found very great difficulty in preventing the escape of the electric charge, given to the conducting wire, or as they more picturesquely said, "to prevent the electric fire from mixing with the atmosphere." However, it was quite possible to send intelligible messages over a limited distance.

Elderly people have sometimes remarked to me that the puzzle to them is how it is possible to send words along a wire. One lady recently said to me that wireless telegraphy seemed to her more strange, for it beat her to think how noiseless words could go through the air from one place to another place distant hundreds of miles. I pointed out that even as I was speaking, no words were really passing through the air between us. I was merely causing the molecules of air to vibrate in a particular manner, and these vibrations were mechanically operating her hearing apparatus, the nerve sensations produced by this being unconsciously interpreted by her brain. In a similar manner we may picture wireless telegraphy to be the setting up of electric waves in the ether, instead of sound waves in the air, and these electric impulses arriving at the distant point operate an apparatus arranged to receive them.

But to leave wireless telegraphy for the present, perhaps a simpler way of looking at ordinary telegraphy is to consider it merely as a means of producing prearranged signals at a great distance. We often carry this principle into everyday life, as, for instance, when a man arrives home his

household may know who is at the front door by three short strokes he is accustomed to give to the electric bell. Other people are recognised by different signals, some made intentionally and some by unconscious habit. In telegraphy all that is necessary is that we agree to a code of signals to represent the different letters of the alphabet.

The simplest method of sending signals by electricity to a distance is to arrange at the receiving end an electro-magnet, which, when energised by an electric current passing through its wire, will attract the iron end of a little lever towards it. The opposite end of the lever may be made to strike a gong, or more usually merely to come against a stop, so that a clicking noise is produced each time the electro-magnet attracts the lever. This electro-magnet will therefore make a click if an electric current is sent along a wire from a battery at the distant sending station, and as there will be no attraction except when the current is passing, the lever will be pulled away from the magnet by a spring as soon as the current ceases. It is arranged that when the lever strikes the upper stop it makes a different sound from the one produced when it falls back upon the lower stop. The sounds may be described as click and clack. The sending operator can therefore, by closing and opening the battery circuit, cause the distant apparatus to make as many click-clacks as desired, and these may follow each other rapidly, or they may have a longer space of time between each. For instance, if the sending lever or battery key, which in principle is the same as an ordinary bell-

push, be depressed rapidly three times in succession, three short click-clacks will be heard at the receiving end. It has been previously arranged that three sharp click-clacks will represent the letter S. One short click-clack stands for E, and one click-clack, with a longer pause between the click and the clack, for T. In this way signals have been made up for each of the twenty-six letters of the alphabet, and with these two simple signals, a short click-clack and a long click-clack, it is never necessary to use more than four of these click-clacks for any one letter. There can only be two letters, of course, having one click-clack, and the benefit is given to the two letters which are used most frequently; E being signalled by a short click-clack, and T by a long click-clack, as already stated. Then there can only be four letters made up of two click-clacks each, and these are a short and a long click-clack for A, a long and a short for N, two short ones for I, and two long ones for M. Eight other letters are made up of three click-clacks each, arranged in different orders, while the remaining twelve letters each require four.

The Morse telegraph apparatus, which does all the hard work in this country and in the United States, is nothing more than the simple electro-magnet and lever, as just described. This telegraph system is named after its inventor, who will be mentioned later. When one hands in a message in London for delivery in Edinburgh, the sending operator in London merely closes and opens his battery circuit according to the code already described, and at the Scottish capital the receiving

operator listens to the click-clacks, spelling out each letter and noting down the message thus signalled. That is to say, the person desiring to send intelligence to a distant friend writes down his message in ordinary writing, hands it in at the nearest telegraph office, where the operator's brain transforms the message into telegraphic signals, known as the Morse code. An electric current under the control of this operator then causes a distant electro-magnet to move a lever, producing a series of click-clacks, which the receiving operator translates into ordinary alphabetical letters, and again constructs the words of the message, which is written out once more in ordinary writing and delivered to the addressee. It is very probable that ere long this transformation to and translation from the Morse code will be entirely dispensed with for ordinary messages, and that the sending operator will directly control a distant type-writing telegraph instrument. The message, printed in letter form by this receiving apparatus, will be taken off the machine and delivered to the addressee just as it is received. In some measure this has long been the practice on the Continent, but the message is there printed on a narrow tape, and this is then pasted on to a telegraph form.

At the present time it is the simple Morse sounder that is in general use both here and in the United States for all ordinary messages, but in order to cope with long press messages, &c., it is necessary to send the signals at a greater speed than can possibly be done by hand. For this purpose an automatic transmitter has been long in use. At

the sending station a long paper ribbon or tape is first of all prepared by an operator using a perforating or punching machine. Small holes are punched in this paper ribbon to represent the Morse signals. The perforating machine has three levers or keys; one key punches holes to represent short clicks or "dots," another punches holes to represent long clicks or "dashes," while the third key represents a letter space. When the Morse signals of a message have been prepared on this perforated tape, it is then run through an automatic sender, which makes and breaks the battery circuit far more quickly than any operator could do by hand. The perforated tape is run through this transmitter by clockwork, and is able to transmit, in one minute, signals representing as many as from two hundred to four hundred words. What is happening at the receiving end? Who can hope to decipher signals coming in at the rate of about seventy clicks in every second? Such a task is, of course, beyond the power of the most expert operator. It is a human impossibility. A special receiving apparatus is therefore required, but this can be very conveniently arranged. It is only necessary to cause the end of the little lever in the Morse sounder to make a mark on a paper ribbon each time the lever is actuated by the electro-magnet, and thus leave a permanent record of its rapid up and down movements. We therefore place a small wheel on the free end of this lever, and allow the wheel to rest in a little well of ink. When the other end of the lever is attracted down by the electro-magnet, this small wheel is raised against

a paper ribbon, which is being moved along at a constant speed by clockwork. As long as the little wheel is kept against the moving paper a line will be marked along its centre, so that by making and breaking the battery circuit this little wheel can be caused to make long or short strokes along the centre of the paper. In this way the movements of the automatic transmitter at the sending end are recorded at the distant station by this little Morse-inker.

It is, of course, possible to send signals by an ordinary hand key to the distant Morse-inker, but no advantage is gained, for in this case the receiving operator is quite as able to translate the clicks into letters as the sending operator is to transform the letters into the Morse signals. The automatic transmitter and its distant companion the Morse-inker are of very great service in connection with the quick despatch of press messages, &c. But for the invention of these instruments the Post Office authorities would require to have far more long telegraph lines connecting important centres.

There have been many very ingenious inventions in connection with high-speed telegraphy, but the simple Morse-inker still holds the field, its very simplicity being its advantage. By one of these recent inventions the receiving apparatus writes the message in ordinary characters at the almost incredible speed of forty thousand words per hour. Two hundred thousand letters of the alphabet in one hour! A tiny mirror, the movements of which are under electrical control from the distant sending station, throws a spot of light on to a sensitised photographic paper. This spot of light traces out the letters of the ordinary

alphabet. When the paper is chemically developed, which process is automatically done by the receiving instrument itself, the message upon the paper may be read by any person. The advantage of having the message in ordinary writing is practically lost, however, as far as press messages are concerned, for it is necessary at the receiving end to make out manifold copies of the message for distribution to the different newspaper offices, and an expert operator can decipher the Morse code practically as quickly as the writing of this special telegraph. The object of this machine is to attain a high speed, so that a sending tape is prepared to control the battery current.

There are many other forms of telegraph apparatus, but I shall only mention one other at this point. Many readers may have seen at one of the exhibitions or elsewhere a very interesting form of hand-writing telegraph. The sender writes his message upon a sheet of paper with an ordinary pencil which is attached to two light levers. The motion given to these levers is electrically transmitted to the distant receiving instrument, where a pen, controlled by two similar levers, traces out the letters made at the sending station. This apparatus has a distinct advantage over ordinary telegraph instruments in being able to reproduce a picture or sketch of any kind made at the distant station. It can also reproduce a signature in exact duplicate, and it has been suggested that one might sign a cheque, distant hundreds of miles, but one would require to have implicit confidence in the individual at the receiving end, that the transmitted signature was not being appended to anything but what the sender intended.

The construction and upkeep of long telegraph lines involves a heavy expenditure, so that the more messages that can be sent over a single line the more valuable that line becomes to the Post Office authorities. The automatic transmitter, however, is already sending the messages as quickly as can be ever possible; indeed, it is capable of making the dots and dashes faster than they can pass along the line if the distance be great. If we have the signals already following at each other's heels as close as they can get, what more can we hope to do? Send several messages at one time! It does seem impossible, and yet it is quite a common practice to send four different messages over one single wire simultaneously. Two of the messages are travelling in one direction and the other two messages in the opposite direction. To make the matter quite clear we may picture four operators sitting together at the London end of a wire which stretches northwards to the Scottish capital, where four other operators are seated. Two of the operators at London are sending separate messages to two of the operators at Edinburgh, while the other two London operators are receiving separate messages from the other two Scotch operators. Four distinct messages travel over this one simple copper wire, and yet there is no confusion. I shall endeavour to give some idea of how this is accomplished, but to give a detailed explanation would necessitate a rather complicated diagram which I fear would only be a worry to the uninitiated.

What really happens is this, the two outgoing messages from the London end do not affect the two receiving instruments at that end at all. We may

picture the two receiving instruments as being electrically shielded from the outgoing current. They are so placed in connection with the line wire that the outgoing currents have no inducement to pass through them, and as electricity will take the easiest path these currents make straight for the distant end of the line wire, a clear path being offered to them there. But why do the two receiving instruments at the distant end not attempt, each on its own account, to translate the two messages? The secret is that the two instruments are not the same, and the two sets of electric impulses sent out by the sending station are not the same either. The first operator at the sending end can only affect one of the distant receiving instruments, while the second operator is sending a current which will only affect the other distant receiver.

Perhaps the best mental picture one can form of this "quadruplex" system of working, without learning all the detail of wiring, &c., is to think of a constant current flowing on the line, and the instruments so arranged that neither of them is moved by this current. If, however, there is any change made in the direction of the current No. 1 receiver is moved, but the other is not affected. No. 1 sending operator may therefore keep changing the direction of the constant current at will, and in this way send signals to No. 1 receiver at the distant end. To what then will No. 2 receiver respond? It is so arranged that it will move with any alteration in the strength of the constant current, so No. 2 sending operator must have a key by which he can alter the strength of the current at will, and in this way he can send signals

to No. 2 receiver. The same arrangement is made between the two sending operators at the Edinburgh end and the two receiving instruments at the London end.

Many important lines are quadruplexed in this way, and every line of importance is at least "duplexed." The duplex system is just half of the quadruplex, there being only one sender and one receiver at each end. By the duplex system only two messages are sent simultaneously, one in either direction. We are indebted to the Austrian telegraph engineers for making duplex working a practical system, although we do not now use their original methods.

Several inventions have been patented, whereby a great number of messages may be simultaneously sent over a single line, but as none of these instruments are at present in everyday use, I shall merely mention the general principle of one such system in passing.

The idea in this case is to use telephone receivers in place of the ordinary telegraph instruments. As many as a dozen telephone receivers may be attached to the one-line wire, and each telephone may be arranged to reply only to one particular electric impulse, which will affect only this one and none of the others. That is to say, a particular electric impulse causes No. 1 telephone to hum a sound, while all the others remain silent; No. 2 has also a particular note of its own, and so on. It only remains to give each operator at the distant end a special battery key, which will set up the necessary rate of electric impulses to move one of the telephone receivers. Each operator can now work away on

his own account, knowing that his signals will only affect one particular receiver at the other end. The signals used may be the ordinary Morse code, the telephone receiver giving long and short notes.

Returning to the ordinary telegraph business of to-day, we shall find many other points of interest. When Morse signals have to be sent to very long distances it is usual to place a "relay," or repeater, midway between the stations. The relay is in construction identical with an ordinary Morse sounder, having an electro-magnet operating a small lever. This lever is so arranged that instead of the free end of the lever merely knocking against a stop, it thus completes an electric circuit and allows the current from a local battery to pass on to the line wire. That is to say, the current sent out by the distant operator merely operates this midway relay, which sends on a fresh current at each stroke, to the distant receiving instrument. The relay is in fact an automaton which imitates the movements of the distant operator. If he depresses his sending key, thus switching the battery current on to the line wire, then the relay at the "half-way house" moves its lever, and switches on its local battery current to the second half of the line wire.

With our climatic conditions in Great Britain it is not easy to send direct signals to a greater distance than four hundred miles, but the introduction of a repeater controlling a second battery helps us out of the difficulty. With the high-speed signals sent out by the automatic transmitters it is found advisable to introduce a repeater at every two hundred miles. On trying one long line, without any repeaters, the

Post Office authorities found that the highest speed at which the direct line would carry the automatic signals was one hundred words per minute; but by introducing one repeater on the way, it was found that the speed could be increased to four hundred words per minute.

There is a further use for the repeater. London has daily news arriving from abroad, and it is necessary to distribute this to all important towns. Much of the news for each town is identical, so that it is very convenient to run one single wire through a number of large towns, each town receiving the signals and at the same time operating the next section of the line. For instance, a line is run from London through Leeds, Newcastle, Edinburgh, Glasgow, Dundee, and Aberdeen, and in this case it is not necessary to put a repeater at each town, there being only one at Leeds, and another at Edinburgh. All these towns receive the news simultaneously from one automatic transmitter in London.

To be able to operate a light relay by sending a weak current is a most convenient arrangement for many purposes, for we can thus control, from a distance, the current of a more powerful local battery.

The Morse system of telegraphy is likely to hold the field until displaced by some simple and reliable form of typewriting telegraph. The Morse alphabet is so easily learned, and the telegraph apparatus is so very simple. We are indebted to our American cousins for the Morse system, and it has quite displaced an English system set afoot about the same time.

Samuel B. Morse, an art professor in New York,

was the inventor of this remarkably simple system, although the idea of using an electro-magnet and lever to make signals had been suggested six years previously by Professor Joseph Henry (U.S.A.). When Morse was on a return voyage from France to New York in 1832, a fellow-passenger had with him an electro-magnet and a battery, and it so happened that he showed these to Morse. It seems to have occurred to Morse then that an electric telegraph would be possible; but five years elapsed before he had a short experimental line erected, while the first commercial line was not constructed till 1844.

In Great Britain inventors had set off on quite a different line; and although the English needle telegraph is fast becoming obsolete as far as Post Office telegraphs are concerned, it may be of interest to trace this line of invention from its source.

It had been known for many years, indeed since 1820, that a magnetic needle placed near a wire carrying an electric current was deflected to one side or the other according to the direction in which the current was passing in the wire. This simple phenomenon, which is of the greatest importance, has been mentioned more fully in the Introduction (chapter i.), and has been referred to in some of the intervening chapters. Shortly after this discovery had been made known, several people, including the great French mathematician Laplace and Professor Ampère of Paris, suggested that intelligible messages might be conveyed to a distance by sending electric currents along connecting wires and thus causing little magnetic needles at the distant ends of the wires to be moved. The first idea was that a separate

wire and magnetic needle would be required for each letter of the alphabet, and an instrument of this kind was actually exhibited in Edinburgh about 1830. It was clear that the expense of carrying out such an elaborate set of connecting wires would be quite out of the question for ordinary business purposes.

Twelve years later a German nobleman, while acting as German Ambassador in St. Petersburg, saw some of the early attempts at telegraphy, and thinking the matter over, he arranged an instrument with five needles to give signals according to a certain code. This instrument is still preserved in the Academy of Sciences at St. Petersburg.

While W. F. Cooke, an officer in the British army, was on holiday in Heidelberg, he saw one of those five-needle telegraph instruments, and he was so much impressed with the possibility of a practical telegraph that he set about trying to devise a simple and reliable system. Coming back to London he consulted Professor Wheatstone of King's College, and these two gentlemen together devised a five-needle telegraph system which dispensed with all code signals. The five needles were arranged across the centre of a diamond-shaped board upon which the letters of the alphabet were printed. By deflecting two needles towards each other they were made to point out the desired letters on the board. The original Cooke and Wheatstone instrument is preserved in King's College (London), while the Post Office have also some of the early needle instruments.

As it cost about £300 per mile to fit up the wires for a pair of these telegraph instruments, it was clear that there could not be any extended use of them

unless the expense could be considerably reduced. By abandoning the idea of the needles pointing out the letters of the alphabet, Cooke and Wheatstone arranged an instrument with two needles, devising a suitable code of signals. Finally they adopted a single-needle instrument with which they could use the Morse code. If the needle was deflected to the left it represented E, just as in the Morse a short stroke or "dot" stands for the same letter. If the needle was deflected to the right then T was understood, being represented in the Morse code by a long stroke or "dash." If one knows the Morse code, one also knows the needle alphabet, provided the simple fact that a left-hand deflection is equivalent to a dot and a right-hand movement to a dash is kept in mind.

In this needle-telegraph instrument the little magnet is mounted on a spindle which passes through an upright board. The magnetic needle is placed at the back of the board, and stands vertically. It is surrounded by a coil of wire, but free to move inside the coil. On the other end of the spindle, projecting through to the front of the board, is fixed an indicator, so that the movements of the little magnet are known by watching this indicator, which moves with the magnet. What could be simpler? A coil of wire and a magnetic needle are the only essential parts for receiving the signals. The transmitter at the distant end may be any suitable arrangement of key for reversing the direction of the current.

The needle telegraph is entirely a British instrument; it first came into use in London about the same time as Morse's sounder found a footing in

New York. The American invention has proved itself the superior, for it has replaced the needle telegraph in our own telegraph offices. We do not find the needle telegraph in use to-day except for communicating with small country districts, where there is no large demand made on the telegraph lines.

The needle instrument still holds an important position in railway signalling; it was in that department it first gained a business footing. A special needle-telegraph instrument is also used in railway signal cabins for working the "block system." In this instrument it is arranged that the needle when deflected to the left or right remains in that position till released by the distant sending key. The needle can therefore take up three different positions, its upright or normal position, slanting to the left, and to the right. Three messages are permanently printed on the dial of the instrument, arranged so that when the needle is upright it is pointing to the words "Line blocked," to the left "Train on line," and to the right "Line clear."

The block system is very simple. Imagine a block or section of the railway track with a signal cabin at each end. These we shall call No. 1 and No. 2 cabins. When No. 1 desires to send on a train he asks No. 2 by means of another telegraph instrument if he may do so. If the way is clear, No. 2 will set the block instruments to "Line clear," and at the same time he will lower his outdoor signals. The block instruments in his own and No. 1 cabin work in sympathy with each other. As soon as No. 1 allows the train to enter the section he moves the block instrument to "Train on line," and this signal

remains permanent on both instruments till No. 2 has allowed the train to pass out of the section, when he moves the indicator to "Line blocked," and at the same time sets his outdoor semaphore to "Danger." The advantage of the block system is that the information given by the one signalman to the other remains visible on the block instruments until such information has been acted upon. It relieves the signalman of the necessity of remembering the last information sent by his neighbour, but it does not relieve him of all responsible action. If the block instrument is pointing to "Train on line," he is not prevented from sending on another train in error, but he has no excuse for such negligence.

While the needle telegraph has become practically obsolete as far as ordinary telegraphy is concerned, we shall see in the succeeding chapter that in a more sensitive form it has made ocean telegraphy a practical success. In this achievement it has scored over the Morse instrument.

In addition to these outstanding telegraph instruments there were many others invented. We see one old-fashioned friend still surviving in some rural districts in the form of the A B C dial telegraph. In this instrument an indicator is moved round a circular dial in clock fashion, and is made to point at any desired letter of the alphabet, which is printed around the dial. As the indicator can only be moved in one direction, it is a long journey from B to A, and so messages can only be very slowly spelt out.

Another idea which came into practice on some short lines was a chemical telegraph, which was very similar in principle to the Morse-inker, but instead of

a moving lever there was merely a stationary metal point rubbing against a moving tape. In this case the tape was made of calico, and was soaked in some chemicals which, when decomposed by an electric current passing through them, turned to a dark colour. When a momentary current passed from the metal point through the tape to a metal roller over which it was being drawn by clockwork, then a mark was made on the tape. In this way the Morse signals could be marked on the tape by operating a sending key at the distant station. It was claimed that as there was no moving lever as in the Morse-inker, this chemical telegraph could be worked at a higher speed, but it never came into general use. A friend tells me that he can well remember one of these chemical telegraphs at work in Glasgow, long before the Government took over the telegraphs. This instrument was probably working in connection with Edinburgh, a distance of over forty miles. Very possibly this chemical telegraph was discarded because of the necessity of using a specially prepared tape.

Had the Government not taken over the telegraphs, there would doubtless have been many different classes of telegraph instruments at work to-day, for each private company would have endeavoured to put forth some special claim for quick despatch of messages by instruments of their own.

It was very well for us that the Government did take over the telegraph system in 1870, as otherwise we should not have been able to send telegrams to small country districts in which the business would not have been sufficient to induce a private company to erect lines.

It may be that some readers have been wondering where the necessary complete electric circuit is, when only one wire is used to connect two distant telegraphs together. It was naturally supposed at the outset that a return wire was required, but one experimenter accidentally discovered that if the two ends of the wire were given a good connection with the earth, the circuit was as complete as though a return wire existed. As a matter of fact, if a wire is erected, say, between London and some distant town, and at the latter place the wire is connected to a galvanometer, which will indicate the strength of an electric current passing over the line to it, it will be found that the current strength is much greater when the earth is used in place of a return wire. In order to picture this earth connection, we need not suppose that the electric current rushes back from the one end of the wire through the earth to the other end, for we may imagine the earth to be as a great reservoir. We then picture the current being dissipated at the one end of the wire, and fed on at the other end, the battery acting as a pump. In order to get a good earth connection it is necessary to attach the ends of the wire to large metal plates, which are sunk in the moist subsoil, or if the wires be attached to water-pipes, &c., the result is the same.

In the smoke-rooms of many of the large hotels and clubs in London one finds a very compact little instrument busily engaged printing off the news of the day on a long sheet of paper. A little wheel carries the letters of the alphabet in rubber type upon its periphery. This wheel spins round and stops in any desired position, then quickly moves forward and

prints the letter on the paper. The necessary energy is supplied by clockwork in the instrument, but its actions are electrically controlled from a distant sending station. The controlling current is operated by keys similar to those of a piano, so that the sending operator does not require to learn a code, while any person can read the message, printed by the little revolving wheel in ordinary Roman type, at the receiving end. It is interesting to watch the little type-wheel at work. After spinning round at a very rapid pace and stopping with the desired letter in position, it impresses it on the paper and then moves along the space of a letter, or if at the end of a word it makes two steps to the right. When it reaches the end of a line it springs back to the left-hand side of the paper once more, while the paper is rolled up to bring it in position for the next line.

While this instrument serves a very useful purpose in distributing important items of news to hotels, &c., it is not considered equal to the demands of the Post Office as a type-printing telegraph. So far any page-printing telegraph instrument has been either too complicated in its mechanism, or not sufficiently reliable in its action, to warrant its adoption by the Post Office for ordinary work ; but many inventors are at work upon the solution of this interesting problem.

CHAPTER XIV

TELEGRAPHY BY SEA

The necessity for an elaborate cable—Why one conductor only can be used in a long cable—The three pioneer Atlantic cables — Submarine mountains — An interesting experiment with a thimble as a battery—Lord Kelvin's grand achievement—The syphon recorder at work—A strange suggestion—Repairing a faulty cable—Some curious finds in faulty cables—Code messages—The cables of the world

In telegraphing across land it is very convenient to be able to connect two distant telegraph instruments together by merely stretching a bare metal wire overhead and supporting it on poles. It is only necessary to support the wire on porcelain insulators in order to prevent the current leaking off the wire, for the surrounding air is an insulator and will not conduct away the low-pressure current used in telegraphy. When it is desired to connect together two telegraph instruments which are situated on the opposite sides of a great ocean the conditions are not so simple.

It would be useless to lay a bare metal wire along the bed of the ocean from the one place to the other, for the water would conduct away the electric current from the wire and dissipate the electricity in the earth. It therefore becomes necessary to insulate the wire from the water, and this can only be done by covering the wire with some non-conducting

By permission of *The Commercial Cable Co.*

LAYING A SUBMARINE CABLE

Landing the shore end of an Atlantic cable

material. The most convenient substance to use is gutta-percha, which makes an excellent insulator, and is, at the same time, very pliable and easily handled. The copper wire encased in gutta-percha is all that is required as far as the electrical properties of the conductor are concerned, but the cable must be able to stand some pretty severe handling in the laying of it, and it must also be equal to the strain put upon it by strong tidal currents, &c. The cable must therefore have a strong outer casing or armouring as a protection for the conductor and its insulating material. This is supplied by a sheathing of iron wires twisted round and round on the outside of the insulating material, and giving the finished cable an appearance similar to that of an ordinary wire rope. Before the iron sheathing is wound on, the gutta-percha with its enclosed conducting wire is very carefully wrapped in cotton tape and soft cotton yarn, then a strip or ribbon of brass is wound spirally over that, and again more cotton tape and a layer of tarred hemp. On the top of all these comes the iron wire protection, which is also well tarred.

Early cables contained one single copper wire to act as the conductor, but it was soon found better to make the conductor up of seven separate strands of copper wire, for there was then less risk of a total break of the conductor from any overstrain. As there is considerable expense in manufacturing the protective part of the cable, it naturally occurs to one that it would be an advantage to enclose several sets of insulated conductors inside the one armouring, and thus supply connections for a number of telegraph instruments. This cannot be done in long cables

such as the Atlantic ones, for the electric current sent along one wire would induce a similar current in the neighbouring conductors. For shorter cables, however, such as those across the North Sea, as many as four separate conductors are placed in the one cable, and for very short distances, such as across rivers, as many as twenty conductors may be enclosed inside the one sheathing.

While only one conductor can be enclosed inside an Atlantic cable, it is possible to "duplex" the line, as described in the preceding chapter. There is then a sending and a receiving operator at each end, so that the cable is carrying messages simultaneously in each direction over the one conductor.

When one thinks of the very great difficulties connected with the laying of the first Atlantic cables, how one attempt after another had to be made, one can well understand the great interest and excitement evinced both here and in America, when at last, in the autumn of 1858, the first telegraph message was successfully sent across the great Atlantic. After a short but busy life of three weeks this pioneer cable became quite dead. It had carried over seven hundred messages, but had never been opened to the public for business. All attempts to repair it proved hopeless.

It was eight years before another telegraph message crossed the Atlantic in 1866. In the previous year the second cable was laid, but it parted in deep water after about two-thirds of it had been successfully submerged, and the engineers were forced to abandon it. However, after the 1866 cable had been successfully laid, it was found possible to pick up

the end of the 1865 cable and complete it also. Although these were the earliest Atlantic cables, many shorter ones had been laid in other places, there being about one hundred submarine cables in existence by 1866. It really took more than a year to lay the first Atlantic cable, but having gained by the experience and difficulties of these early pioneers, we can now lay a complete cable across the Atlantic, from Ireland to Nova Scotia, in less than three weeks' time. These three pioneer cables are now lying dead at the bottom of the ocean, but they have indeed served a useful purpose. We have now from fifteen to twenty cables carrying intelligence between Europe and America. Not only is the Atlantic spanned; submarine cables are laid in the Pacific, the Mediterranean Sea, the Black Sea, the Arabian Sea, the Indian Ocean, the North Sea, the English Channel, &c.

The great irregularities in the depth of an ocean make cable-laying a very difficult task. Although the average depth of all the oceans is about two and a half miles, a depth of over seven miles has been found in the South Atlantic, and about five miles in the North Atlantic. A cable ship will be laying a cable at a depth of one mile below the sea's surface, when it finds that this is the top of a great submarine mountain, and, as the ship continues to lay the cable down the mountain side, it soon becomes apparent that this mountain is two and a half miles in height, for the cable is found to have reached a depth of three and a half miles below the surface of the sea. A cable ship keeps in constant communication with land, through the cable it is laying, during the whole voyage, so that those on board hear

of any important event occurring on land in their absence.

The actual time taken for a signal to cross the Atlantic is very small indeed. By joining up several cables, a signal has been sent through a distance of eight thousand miles in one second. On one occasion a very interesting experiment was made to demonstrate how very sensitive the cable telegraph instrument is. Two lengths of Atlantic cable were joined together at their Newfoundland ends, the other two ends being in one cable office in Ireland. One end of this double cable was connected to a telegraph instrument, while the other end was left free to attach to a battery. A temporary battery was made by filling a silver thimble with sulphuric acid and placing a tiny piece of zinc in it. When this miniature battery was connected to the cable, now measuring about four thousand miles, the telegraph instrument was operated at once, the current having travelled to Newfoundland and back in order to get from the thimble to the telegraph apparatus. This remarkable experiment is recorded in "Submarine Telegraphs," by Charles Bright, F.R.S.E., who states that "the deflections were not of a dubious character, but full and strong, the spot of light traversing freely over a space of twelve inches or more, from which it was manifest that an even smaller battery would suffice to produce somewhat similar effects."

The spot of light mentioned in the preceding sentence has reference to the mirror galvanometer used for receiving the cable signals. An ordinary galvanometer is simply a magnetic needle suspended inside a coil of wire; the needle is deflected to left or right

according to the direction in which a current is sent through the coil. In the preceding chapter we saw that the needle telegraph is a simple galvanometer. A strong current is able to deflect a heavy magnet, but it was found that an ordinary galvanometer was too clumsy to reply to the currents arriving at the distant end of a long submarine cable. Lord Kelvin, who was then Professor William Thomson, invented a very light galvanometer to overcome this difficulty. In this instrument the magnet was made so very small that its movements could not be readily seen, so he attached a very tiny mirror to the magnet, and then throwing a beam of light from a lamp on to the mirror, he caused a spot of light to be reflected by the mirror. This spot of light falling upon a distant screen would have quite a large travel, just as a boy by using a small sun-reflector can make a spot of light sweep across a large building, by a very small turn of his wrist. If the spot of light from the mirror is arranged to rest normally at a line on the centre of the screen, then its movements to the left and right of that central line could easily be distinguished. It was in this way that all intelligence was conveyed across the Atlantic for the first nine years.

It became rather tiresome to the eyes watching this spot of light dancing to and fro, indicating the Morse signals, a movement to the one side signifying a "dot," and to the other side a "dash." It therefore occurred to the inventor of the mirror galvanometer that he might cause the tiny magnet to move a pen across a paper ribbon and thus leave a record of its deflections to left and right. To the ordinary man this would seem an impossible task. The mirror

galvanometer was so very delicate it surely could not be expected to move a pen. It certainly could not move a pen of any ordinary make, but Lord Kelvin used a very small glass tube, which could be rocked to one side or the other by silk fibres attaching it to the little magnet. This little glass tube was made to act like a siphon, its one end dipping into a small well of ink, and the other end placed immediately over a paper ribbon, which was moved along at a constant speed by clockwork, just as in the Morse inker, described in the preceding chapter. In order to make a constant stream of ink pass from the tiny siphon on to the paper, it was found necessary to electrify the ink, by means of a small static machine. Later it was found that by giving the little siphon a vibratory motion a similar result was obtained. The little siphon while in its normal position would mark a straight line along the centre of the moving paper ribbon, but if an electric current reaches the coil of wire, the current being sent from the other side of the Atlantic, then the little siphon will be rocked to one side or the other, according to the direction in which the current is sent around the coil. In this way the movements of the little magnet to left or right are traced out on the paper ribbon, appearing as curves above or below the central line when reading the paper lengthwise.

In describing the siphon recorder I have, for the sake of simplicity, imagined the glass siphon to be controlled by the tiny permanent magnet of the mirror galvanometer, but in practice the construction of the instrument is different, although the principle involved is identical. In order to get as much advan-

tage as possible from the incoming current the order of things is reversed. In the mirror galvanometer we have a small permanent magnet controlled by a weak magnetic field produced in the coil of wire by the incoming current. This is sufficient to cause the tiny magnet and its mirror to turn round, but these together only weigh about one single grain. This effect will not be sufficient to satisfactorily move the glass siphon. Therefore, instead of depending upon a weak permanent magnet to be controlled by a weak magnetic field set up by the incoming current, there is a powerful magnetic field permanently produced by a large stationary steel magnet, and between the poles of this magnet is suspended a light coil of wire which becomes a magnet whenever the incoming current traverses it. This coil is then attracted by the poles of the stationary magnet according to the direction in which the current is passing round the coil. In this way a more energetic movement is obtained from the incoming current, and the siphon is satisfactorily rocked to one side or the other.

The invention of these sensitive telegraph instruments by Lord Kelvin is of historical importance, for it would have been quite impossible to have sent intelligible signals over long submarine cables by any ordinary piece of mechanism. All important cables now use the siphon recorder, while the mirror galvanometer still holds the front rank as a sensitive testing instrument.

A modern cable will transmit messages at a rate of about fifty words per minute, which is twice as much as could be accomplished on the early cables. Automatic transmitters are used on all long cables,

the advantage gained being not so much a matter of slightly increased speed, as a regularity of signals which cannot be given by hand.

In the early days of cable laying, it was suggested by an outsider that the Atlantic cable should be buoyed up at intervals across the ocean, and that the cable should be tapped at such points, so that a passing ship might if necessary attach a telegraph instrument at one of these places, and thus communicate with land. Needless to say the project was quite impracticable. Had some one then suggested that in the near future ships would be able to telegraph to land without any connecting cable or wires, the idea would have been considered far more absurd than the suggestion just related.

Having once laid the cables, the expense of carrying on the business does not only mean the working of the apparatus on land, for a whole fleet of large steamers is required to maintain the cables in perfect working order. When a fault occurs, its position can be determined by testing the cable, and noting how much resistance is offered to the passage of an electric current. The exact resistance offered by one mile of the cable is known, so that the length through which the current is going, before escaping to earth at the faulty place, can easily be determined. A steamer then proceeds to this point, and rakes the bottom of the ocean with a grapnel until the cable is caught, possibly at some little distance from the fault. It is then brought on board and cut, and when tested one or other of the ends will enable messages to be got through to land. This end being found to be quite sound, is sealed up and dropped

overboard with a large buoy attached. The other end is gradually picked up, and it may be found to be quite severed from the main part of the cable. If so, then the other end of the cable has to be picked up as already explained. Then a fresh piece of cable is spliced on, and tested through to land, the steamer having thus got in touch with both shores. The steamer makes her way back to the floating buoy, paying out fresh cable as she goes. It only remains to make the final splice, and the cable is once more complete from shore to shore.

It has happened that a dead whale has been found entangled in a faulty cable, and on one occasion when raising a faulty cable in the North Sea, the repairing steamer brought to the surface a small sailing vessel. The teeth of sea-monsters have often been found embedded in faulty cables, but the chief enemies of the cable companies are small marine insects or worms, which can slip in between the wires of the outer sheathing, and bore their way through the insulating cover, thus causing a leakage. These marine organisms are like soft-bodied snails, some being about the size of a pin's head.

In the early days of ocean telegraphy it cost twenty pounds to send a message across the Atlantic, the charge being one pound per word and the minimum number of words allowed being twenty. We can now send messages of any desired length at the rate of one shilling per word, and by using a telegraphic address and a single code word quite a lot of intelligence may be sent. Allowing two words for the telegraphic address and one code word for the message, the total cost is three shillings. Several

standard codes exist, but business houses often arrange special codes of their own, while any person may arrange a temporary code with a friend. By such means a single word may mean a great many words, and it is recorded that on one occasion a message was sent in which one word stood for a pre-arranged message of two hundred words.

The total length of submarine cables at present in use cannot be far short of two hundred and fifty thousand miles. I have made a rough calculation of the total length of copper and iron wires used in the manufacture of these cables, and this gives a total of somewhere about forty millions of miles. It is difficult to realise what this immense number means. If we wound the wire around our earth at the equator, we could provide her with two thousand belts. If it took a steamer a year to lay one complete girdle, it would require twenty centuries to complete the whole task. I merely use these pictorial representations as an aid to grasp the immensity of the work involved in the manufacture of the world's submarine cables.

There is one difficulty in sending electric currents through long submarine cables, and for the present this may be described as a lagging behind of the current. To obviate this, "condensers" are introduced at the ends of the cable, but as this difficulty is more serious when using the cable as a telephone conductor, I shall leave the subject over till we are considering telephones.

Photo by *H. W. Mack, Runcorn*

AN AERIAL FERRY

The bridge from which the transporter car is hung is made of steel ropes, and is stretched across the River Mersey (England). The car carries a large number of passengers very comfortably. The cost of electric power to transport the car across the river is only one cent per journey.

CHAPTER XV

TELEGRAPHING WITHOUT WIRES

A seeming impossibility accomplished — Communicating with ships at sea—The medium of communication—How the signals are sent—Where the idea of wireless telegraphy originated—How the electric waves are detected—Coherers and anti-coherers—Transatlantic communication—Some ingenious wave detectors—A receiving instrument without a local battery—The different systems in use—The chief difficulty — A favourite analogy—A new analogy — How wireless instruments are tuned—The practical results—The transmitting station—The antennæ—A curious fact—An entirely different system—Its limitations—The transmission of power without connecting wires

Of all the remarkable achievements of electricity, that of being able to communicate through space with ships far out at sea is perhaps the most wonderful. This does not mean, as was supposed by some at first, that the days of connecting wires are past. Wireless telegraphy has a special field of its own; it gives us a means of communication in circumstances in which no other method can be of any service whatever.

A steamer has left Liverpool for New York, and is already two days out at sea, when some one on land is most anxious to communicate with one of the passengers on board. Only a few years ago any one making such a request at a postal telegraph office would probably have been detained for medical

examination, and yet such a seeming impossibility is an accomplished fact to-day.

To take another illustration, we may picture a large passenger steamer in mid-ocean; having encountered very bad weather, she has met with some misfortune which disables her, and she is driven by the storm far off her regular course. It is probable that with some necessary delay her engineers can repair the damage, but in the meantime the captain can send a wireless message to land, explaining her non-arrival. If necessary he could ask for assistance, either from land or from some other steamer.

It is very convenient that ships can communicate with each other though not within sight of one another, and it is in being able to communicate between ship and ship, and from ship to shore, that wireless telegraphy has a large sphere especially its own. Wireless telegraphy may be used on land, but here it comes into competition with ordinary telegraphy, which has distinct advantages. Whether or not wireless telegraphy will seriously compete with submarine cables remains to be seen; it seems more probable that it will become a useful adjunct to the ocean cables.

What is taking place when a wireless message flies through space? It has already been pointed out in chapter xiii. that when one person speaks to another the speaker merely sets up certain vibrations in the air, and these so stimulate the hearing apparatus that a series of nerve impulses are conveyed to the sensorium, where the meaning of these signals is unconsciously interpreted. In wireless

telegraphy the sender sets up vibrations, not in the air, but in a something which we call the all-pervading ether, and these ether vibrations reaching to a great distance so affect a receiving apparatus that signals are made, and the operator watching the movements of the receiver may interpret the signals.

For the present we shall be content to know that there is a something which fills all space, that scientists have named it the ether, and that it is the medium for conveying light, heat, and electricity. It is this medium which conveys energy from the far distant sun to us, and it has been possible to calculate the speed of travel of the ether vibrations which we call light. The speed is not much short of 200,000 miles per second, or to be more exact, 186,000 miles in one second. When we come to consider the science of this subject, we shall find that we have practically no knowledge of the nature of this ether, but it is none the less real because of our ignorance. When the ancients sent messages across the country by means of beacon fires, how were the signals transmitted? These ancients were using the same medium as we do in wireless telegraphy. The burning fire set up ether vibrations, and these so affected the eyes of the distant watchers that they received certain sensations, which by experience they recognised as being caused by a bright light at a distance. It had been pre-arranged that when this fire was set alight it would have a certain meaning, and so the signal could be interpreted. During the political election campaign of 1905, a powerful searchlight was used in London to flash

signals into the dark sky, and these were received by watchers in all directions, and when interpreted gave information as to the progress of the two great political parties.

Just as the ear is the receiver of air vibrations, so is the eye the receiver of ether vibrations. The ear can only detect a limited range of air vibrations; the eye can only detect a limited range of ether vibrations. If we wish to send a signal by light to a distance, we must use a powerful source of light, so that we may cause a considerable disturbance in the ether; the same principle applies to wireless telegraphy. But how are we going to disturb the ether so that signals may be carried to a very great distance? It is certainly not by producing the rates of ether vibrations which come within the limited range recognisable by the eye. There are other disturbances in the ether as well as those we call light. We have seen that there is an ether disturbance around a wire carrying an electric current, for when a magnetic needle is placed within the area of this disturbance the magnet is moved bodily into another position. This we call an electro-magnetic disturbance in the ether. Again, if we give an insulated body a charge of electricity, we find that any light object brought near to it is suddenly attracted, indicating a decided disturbance in the ether, which is described as an electro-static disturbance or effect.

The present system of wireless telegraphy is dependent upon this electro-static disturbance of the ether. It originated from some experiments made by the late Dr. Hertz of Carlsruhe (Germany).

Hertz was endeavouring to prove experimentally the celebrated electro-magnetic theory of light, as formulated by Clerk Maxwell some twenty years previously. Up to this time, about 1886, electric waves were known only in theory. Mathematicians had devised means by which the lengths of such waves might be calculated. Their nature and behaviour had been predicted, but the experimentalist could find no means of detecting these electric waves, which were known to exist in the ether when any sudden electrical discharge took place. Hertz discovered a method of doing so. He set up the waves in the ether by means of an electrical discharge from an induction coil; he believed that each time a spark discharge occurred the surrounding and illimitable ether was disturbed. How could these electric waves be detected? One might expect to hear of some very ingenious and sensitive piece of apparatus, so arranged that it would be affected by these imperceptible waves. Instead of this nothing could be simpler; a short length of wire with a small brass knob at each end, and the wire bent round to form almost a complete circle, leaving only a small air gap between the knobs, and that is all. This very simple arrangement enabled Hertz to detect the ether waves set up by the induction coil. Each time there was a spark discharge from the induction coil, Hertz found a small electric spark also occurred between the knobs of his simple wire loop, which was held at some distance away from the induction coil. It was proved beyond any possible doubt that electric waves were propagated through the ether.

It was very soon suggested by several scientists that these electric waves might be used as a means of transmitting signals to a distance without any connecting wires. The scientist did not, however, consider at first that these electric waves could be conveniently used on a large practical scale for ordinary commercial purposes. The discovery of a more sensitive wave detector gave an impetus to the idea of space telegraphy. It had been observed by an experimenter on the Continent that while loose metal filings offered a great resistance to the passage of an electric current through them, this resistance was very materially reduced when electric waves fell upon the filings. If therefore a wire, connecting a battery to a bell, was cut at any point and a tube containing some loose metal filings was inserted in the circuit, the electric current could no longer get across from the battery to the bell. But if electric waves were caused to impinge upon the filings their electrical resistance was suddenly reduced and the battery current was able to cross by this bridge, and cause the bell to ring. How long will the bell continue to ring? Just as long as this bridge is allowed to remain undisturbed. If the filings are shaken the path of the current is broken and the bell ceases. The filings are once more ready to be affected by further electric waves. So all we have to do in order to make signals is to arrange a tube of filings in circuit with a battery and bell, and then send out electric waves from an induction coil which will cause the bell to ring. We can then arrange that as the gong stick returns from striking the bell, the gong stick will also strike the tube of filings or otherwise

shake it and break down the temporary bridge formed by the filings. By such means we could signal the Morse code. The tube of filings has been named a "coherer," signifying that the filings cohere or cling together under the influence of the electric waves. The tube may be made of glass, or any other insulating substance. One wire enters at each end of the tube, and each is attached to a small block of metal. These two blocks are brought very close together, and then the small space between them is very loosely filled with fine metal filings. Any metal will do, but it has been found that nickel filings with a trace of silver act very well. An apparatus such as described, with a simple bell, would not make a very convenient telegraph apparatus, but with the aid of a relay we may connect a Morse sounder or inker to the coherer.

Many different forms of detectors have been invented, but they all have the same duty to perform; to close a local battery circuit when electric waves fall upon the detector. Marconi improved upon coherers, and along with his assistants he developed other methods of detecting the electric waves. It was Marconi who put wireless telegraphy upon a business footing.

One very good form of coherer, used by the Italian navy, consists of a glass tube with small carbon blocks or plugs attached to the ends of the wires, and instead of metal filings there is a bead or globule of mercury between the plugs. When electric waves fall upon this coherer, the mercury coheres to the carbon blocks, and thus forms a bridge for the battery current. One advantage in this form of

coherer is that it does not require to be mechanically shaken to break down this bridge, for the mercury will only cohere to the carbon plugs as long as the electric waves are affecting it. In other words, the mercury tube decoheres of itself immediately upon the cessation of the electric waves. Instead of connecting this mercury tube to a telegraph instrument, it is usual to place a telephone receiver in the circuit, for the current does not last long enough to work any other instrument. Each time the tube coheres there is a soft hum or buzzing sound heard in the telephone, and it is a simple matter to signal the Morse code by short and long sounds. This coherer is very sensitive, and has been used over very long distances. When a powerful electric discharge was produced in Great Britain, one of these coherers on the other side of the wide Atlantic Ocean detected the waves. The transmitter in Great Britain was kept sending out three short signals, representing the letter S, and these were to be sent at certain definite intervals. The coherer succeeded in picking up these signals, and for the first time in the history of the world signals were sent through space from Europe to America.

Why use the letter S as a test signal instead of some more elaborate combination of long and short strokes? The reason for selecting the letter S is that it contains no long stroke, so that should the coherer happen to be affected by any other disturbance, such as lightning disturbing the ether ocean, it would be easily recognised as due to some foreign influence, for all such disturbances would produce longer strokes than those used for the letter S.

It was a remarkable feat getting these signals across the Atlantic, but this did not prove that it would be an easy task to carry on a regular communication. These pioneer signals were transmitted in 1901, and although other signals forming intelligible messages have been despatched and received since that date, we still await the opening of wireless transatlantic communication to the public. It is difficult to obtain information as to how matters exactly stand, for there are rival companies at work trying to solve this important problem. There is not the same difficulty in communicating with steamers crossing the Atlantic, and the public may despatch telegrams or aerograms to passengers on board these steamers, by handing in the message at the nearest postal telegraph office.

As the coherers already mentioned show how electric waves may be detected in wireless telegraphy, there is no need to do more than merely mention one or two other forms of detectors. The necessary loose contact is got in one coherer by a pointed carbon resting on a slightly oxidised steel surface, while a somewhat similar plan is to have a lead electrode resting on a surface of peroxide of lead. Another very sensitive detector is obtained by a revolving disc touching lightly on a column of mercury, which has on its surface a thin film of mineral oil. All these different inventions come under the heading of coherers, but there are others in which the action is just the reverse, and which therefore go by the name of anti-coherers. One anti-coherer consists of a tube similarly arranged to the ordinary filings tube, but with two little blocks or rods of tin between

which there is placed a semi-liquid paste, sometimes composed of alcohol with tin filings and lead oxide. This paste in its normal condition allows the battery current to get across from the one block to the other, but when electric waves fall upon it they produce a chemical action which immediately breaks down this bridge and stops the current. Upon the cessation of the electric waves the paste at once returns to its normal condition and allows the battery current to again pass. The signals are therefore a sudden breaking and making of the battery circuit. If a telephone receiver is connected to the tube and battery, it will be very easy to tell when the battery circuit is broken, for there will be quite a loud click heard in the telephone. Any person using the ordinary telephone may hear the click referred to by depressing the telephone hook or support while the receiver is held to the ear. When the hook or support is depressed the battery current is cut off from the telephone, and it is this stopping of the current causing a sudden change in the magnetic field of the receiver which produces the click. This will be better understood when we come to the explanation of the telephone in the following chapter.

The wireless telegraphist has not only invented sensitive coherers and anti-coherers; he has constructed other entirely different forms of detectors. The most prominent of these is the magnetic detector. To understand this invention we must keep in mind that if a piece of soft iron is continuously revolved in front of a permanent magnet, the magnetic poles of the soft iron piece will keep changing their position at each half revolution. This magnetic

change requires a little time to take place, so that the change somewhat lags behind the magnetising hyste force as it were, or perhaps it is better to picture a certain resistance being offered to this change of magnetic poles. It was discovered that if electric waves fell upon the iron this resistance was almost entirely eliminated, so that the magnetic poles could then change places instantly as it was revolved. If we have a quickly changing magnetic field, then, it will induce or set up an electric current in a neighbouring coil of wire. In this way we can detect the changes in the magnetic field, for we can place a telephone receiver in connection with the coil of wire just described. In a modern receiver of this class it is found more convenient to replace the revolving iron piece by an endless band of soft iron wire. This band is kept passing in front of a permanent magnet, the magnetism of the wire tending to change as it passes from the one pole to the other. This change takes place suddenly when the electric waves from the transmitting station fall upon the moving wire, and as the band is passing through a coil of insulated wire attached to a telephone receiver, this sudden change in the magnetic field induces an electric current in the surrounding coil and the operator hears a sound in the telephone which he has at his ear. The Morse code may thus be signalled from the distant transmitter.

After describing the first coherer with the metal filings, I said that the duty of all detectors was to control a local battery circuit, but this magnetic detector just described is an exception to the rule. Here we have no local battery as used with the coherers and

anti-coherers. Are the incoming electric waves then supplying the necessary energy to operate the receiver? No! They are still merely acting as a controlling force, for we are supplying energy by moving the iron wire in front of the magnet, and the ether waves from the distant station are merely changing the resistance of the iron wire, so that it may be suddenly magnetised and demagnetised. It is true we have not supplied electrical energy by means of a local battery, but have we not supplied it by a miniature dynamo instead?

There is another class of detector which I think will be of special interest; indeed the controlling of these detectors by men distant hundreds of miles from them, and without any connecting wires, seems more like fiction than fact. This detector, which is the last I shall mention here, is dependent upon the fact that, when a rapid to-and-fro or oscillating current surges in a wire, there is a distinct heating of the wire. When the temperature of a wire is increased its electrical resistance also increases, so it only remains to detect this change of resistance in a similar manner to the detectors already described. When a body is heated it takes an appreciable time to cool down again, so how is the wire in this detector to be got ready for a second signal? This is accomplished by making the whole length of the wire that is to be heated of very small dimensions. The wire used for this purpose in the receiver, or "barretter," as it is called, is not as big as a pin's head; indeed it only measures one-thousandth part of an inch in length, and about one twenty-five-thousandth part of an inch in diameter. How can it be possible to make a wire of

these tiny dimensions? First of all a silver wire is made with a platinum core, and this wire is drawn out till the total diameter is about one five-hundredth part of an inch, while the inner core of platinum only measures one-fiftieth of this, or about one twenty-five-thousandth part of an inch. It only remains to lay bare a tiny speck of the inside core, and this is easily accomplished by bending the wire into a loop, and then dissolving the silver off the very tip by immersing it in a strong acid. When the current surges to and fro in this conductor it will only heat the tiny speck of exposed platinum, for it will have an easy path in the silver wire on either side; just as we found in the electric lamps that the conducting wires did not become heated, but that the same current raised the fine carbon filament to a white heat.

Sufficient detail has been given of the various forms of wireless receivers to show that the ground already covered by inventors is very extensive. In describing the different detectors I have purposely omitted the names of the inventors, in order to simplify matters as much as possible; but as one so often sees references in the daily papers and journals to the different systems by name, it may be of interest to briefly mention the more important of these.

The Marconi system includes many forms of coherers, also the magnetic detector, and many variations of these. The Lodge-Muirhead system, while employing similar coherers, has the revolving disc and mercury contact as its own special detector. Formerly one sometimes read of the Slaby-Arco and the Braun-Siemens systems, but these two German couples are now combined together under the Tele-

funken system. This odd-looking word really means spark-telegraphy. The special feature of this system relates to the methods adopted for sending out the electric waves. There are two American systems very often mentioned, the De Forest and the Fessenden. The electrolytic detector with the paste between the tin blocks belongs to the De Forest system, while the barretter with the speck of platinum wire is one of Professor Fessenden's inventions. There are many other names well known in connection with wireless telegraphy—Popoff, Jackson, Armstrong, Orling, Dolbear, Stone, and Artom being but a few of these.

If one pictures a number of wireless stations at work, simultaneously sending out ether disturbances, it does not require a very vivid imagination to predict that there will be a possibility of interference between the different stations. How will a certain receiver know which particular set of electric waves to respond to? This trouble does exist, and indeed it forms the most important problem to be solved by wireless telegraphists. In the early days this trouble was very marked. Some of us have recollections of a demonstration of wireless telegraphy, in which messages were to be transmitted from a distant station to a lecture hall, which demonstration was turned into a farce by a third party intercepting the messages, and signalling some nonsense to the assembled audience. It was an awkward incident, but the motive of the intruder was merely to show that there was a possibility of interference. It was quite a common thing at the outset for the receivers of one system to reply to the transmitters of a rival system. This trouble has in a certain measure been overcome, in some cases

with considerable success, but there is evidence that the trouble has not yet disappeared. The British Post Office authorities have refused licenses to some applicants seeking permission to erect wireless stations at certain points around our coast, on the ground that there would be a risk of interference between the proposed station and some other system already licensed in the same district.

A favourite analogy for wireless telegraphy used to be that of a man shouting to a distant friend. If the friend was within earshot the message reached him, but other persons happening to be within the same range might also pick up the message. The corresponding analogy for the ordinary telegraph suggested that the conducting wire was equivalent to a speaking tube, which directed the message from the sender to one particular point only.

Since the foregoing analogy was first used, there has arisen the very important question of "tuning" the transmitter and the receiver to be in sympathy with each other. It is well known that a body free to vibrate at a particular rate, may very easily be set in motion by producing a sympathetic sound in its neighbourhood. By a sympathetic sound I mean a sound having the same rate of vibration, or, as the poet might say, two sounds whose hearts beat as one.

The blind piano-tuner often rises from his seat at the piano, to alter the position of some article in the room; it may be to turn some glass vase upside down. He hears certain articles replying to certain notes. This selective property of sound waves may be best illustrated by taking a number of tuning forks, mounted upon sounding boards, and placing them at one end

of a table, and then arranging a similar set at some little distance from these. If any one of the forks in the one set be thrown into active vibratory motion, so that it sounds out its note, the same note will be heard coming from one of the forks in the other set. If any one fork is sounded, the corresponding fork in the other set will always respond to it. The reason for this is very simple. Each fork has a definite rate of vibration, according to its construction, and when set in motion it will cause the surrounding air to vibrate at the same rate. These air vibrations reach the other forks, and we may imagine all the forks endeavouring to vibrate under the influence of the air vibrations impinging upon them. It is only the fork which can swing to and fro at the same rate as the surrounding air that will respond. The other forks might try to move with the air, but the second impulse would arrive at the wrong time, and only serve to damp out the energy of the first impulse. With two exactly similar forks we have one setting up air vibrations, the air in turn setting up similar vibrations, and the second fork set in motion by the air, or, in other words, the one fork is able to pick up the signals sent out by the other fork, provided it can move in sympathy with the sending fork.

If the wireless telegraphist can cause a transmitter to set up a definite rate of vibrations in the ether, and arrange a receiver which will respond to that particular rate of vibration, then he has a selective or tuned system.

To return to the analogy of the man shouting to his friend, I think this may be extended so as to

include the question of tuning in wireless telegraphy. When visiting one of our Deaf and Dumb Educational Institutions recently, it occurred to me that we had there a fitting analogy for this subject. The superintendent may select for us a dozen scholars, all of them being stone-deaf as far as the hearing of human speech is concerned. It has been found, however, that not one of the twelve is deaf to all sound; indeed, out of about one hundred and seventy scholars there are only one or two who are really stone-deaf in this sense. Taking the dozen selected by way of illustration, we find that when a very high note is sounded, one or two of the mutes point to their ears, or otherwise indicate that they have heard the sound; the others have not heard it. Some of these, however, respond to a very low note, while to the others it is silence. With patience we find one note to which only one of the twelve responds. We could then send signals to that one scholar without stimulating the hearing apparatus of any of the others. Let us suppose that we have been able to find a note for each of the twelve to which none of the others can respond. In this way we may imagine that we have built up a selective system, and we are able to send signals to any one of the twelve mutes at will. A third party, however, produces another note or a combination of sounds which several of the mutes hear, and while we are endeavouring to communicate with one scholar, this third party keeps disturbing the air in such a manner that our efforts are useless.

We might make further use of the foregoing analogy by supposing that while we have been arranging suitable apparatus for communicating with our twelve

scholars, some one else has been arranging apparatus for some other mutes. Now we find our scholars are picking up signals intended for the other set. Again, while one of our scholars will only respond to one of the notes we are producing, there are many other notes to which he may respond. One of the authorities upon this subject, Dr. Kerr Love, of Glasgow, is making out charts of the "islands" of hearing in deaf mutes. I am indebted to Dr. Love for confirming the physiological side of my analogy. To sum up the matter, it is possible to arrange a wireless transmitter and receiver which will act in unison, and it is quite practicable to make a receiver which will not respond to the same transmitter, but so far it has not been possible to arrange a receiver which will be free from possible interference.

How is this tuning arranged in wireless telegraphy? We must first of all control the electric waves sent out by the transmitter. We must arrange a definite rate of vibration. This could not be satisfactorily done with the early arrangement, which consisted in merely storing up an increasing electric pressure by means of an induction coil, until the insulating air gap was forced to break down, whereupon a sudden discharge took place accompanied by a spark. This was analogous to drawing back a flat metal spring, and suddenly letting it go with a bang. There would be a certain oscillating motion given to the spring, but the bulk of its energy would be spent in the first one or two impulses. This system of transmitting ether waves has been descriptively named by some "the whip-crack method." To use still another figure, this system is analogous to making a sudden

splash in the ether ocean, whereas we require to set up a series of rhythmic ripples to have a tuned system.

If wireless telegraphists had got no further than their first system of transmitters there would have been little hope of commercial success. The tuned transmitter sets up a regular set of definite oscillations in the ether. A very good analogy has been used by Dr. Erskine-Murray in a lecture on wireless telegraphy, delivered to the members of the Institution of Electrical Engineers. "When one child swings another on a swing it gives a series of little pushes, each one being timed to the time of the swing. The swing goes higher at every push, and in the end is swinging more energetically than even a strong man could have accomplished with a single effort. But if the pushes were not properly timed the swing would never attain to motion through a large arc, as some would check while others increased it." This principle of the superposition of small motions was a favourite theme with Lord Kelvin. The analogy of the child on the swing helps one to understand how it is that an untuned transmitter is so much less efficient than a tuned one.

The electrician understands the method of tuning wireless instruments, when he is informed that the capacity and inductance of the receiver must be the same as those of the transmitter, but the general reader will best understand the principle involved by reference to the analogy of the syntonic or sympathetic tuning forks.

When one hears of a tuning fork or other sounding body making, say, twelve hundred vibrations per second, it seems to be an enormous speed of oscilla-

tion, but this sinks into insignificance when compared with the ether disturbance produced by wireless transmitters, for there the speed may reach thirty million vibrations per second. Of course in the former case we are speaking of vibrations in a material body, the fork or the air, whereas in the latter case we are dealing with the ether, which is certainly not matter in the ordinary sense of the word.

What has been the practical result of tuning in wireless telegraphy? Two different receivers placed close together may simultaneously receive different messages from two separate transmitting stations. Again, picture one of our battleships with a tuned transmitter on board, while the receiver corresponding with this transmitter is on another vessel five hundred miles distant. Messages are being sent out to the distant ship, and at the same time another differently tuned receiver on board the sending battleship is picking up messages from a third vessel within close range. This is an immense advance beyond the capabilities of the original untuned system. A receiving instrument is, of course, sheltered from the influence of the transmitter at its own station.

In order to set up as energetic electric waves as possible, there have been many methods devised at the transmitting stations. If we picture the two metal balls or spheres between which the electric discharge takes place, we can then think of a wire being attached to one ball and carried up into the air to a height of two hundred feet or more, while another wire is connected to the second ball and led to earth. One method is to erect a simple wire on a pole, another

is to support a regular network of wires from strong steel towers built to a height of over two hundred feet. Sometimes the wires have been arranged like a great inverted pyramid, while one system employs a great sheet-iron tube, like a factory chimney, reaching a height of over four hundred feet.

It was only when one of the conductors in the transmitter was connected to earth that long distance transmission became possible. Only a few miles could be spanned by the true "Hertzian waves" previously used; these electric waves called after Hertz were produced without any earth connection. Waves of this class would radiate out into all space, whereas those set up by a grounded transmitter, with the receiving instrument similarly connected to earth, would at least keep within the immediate neighbourhood of the earth. Many attempts have been made to direct these electric waves and send them out in one particular direction, and some success has been reported.

When thinking over the fact that in tuned systems the transmitter has to set up a series of oscillations, and especially with the thought of the children's swing analogy, it may occur to some readers that it will take time to produce these electric waves. Undoubtedly more time is occupied in so doing, than is required in the "whip-crack method" of letting the charge go bang, but even then the time in this slower method is measured in thousandths of a second. The time taken to produce these electric waves will therefore in no way interfere with the speed of signalling. That will be dependent upon the capabilities of the receiving apparatus.

In reading any account of the doings of wireless telegraphy one is sure to come across the word "antenna." Possibly one has previously fallen in with this word in connection with insects, whose tiny horns or feelers are called their "antennæ." The electrician uses this same word as being descriptive of his aerial wire or feeler at the receiving station. This aerial wire serves also for the transmitter, in which case it might be termed an emitter, but as the erection is common to both the transmitter and receiver it is convenient to let the word antenna simply stand for the aerial erection.

For distances up to about two hundred miles a storage battery and an induction coil are sufficient to produce the necessary ether disturbance, but where a greater distance has to be spanned, then a steam engine and dynamo are called into play in order to supply a greater energy for the electric waves. One of the transatlantic stations is equipped with a plant of over two hundred horse-power.

It is a curious fact that it requires about twice as much energy to send a long distance wireless message in the daytime as it does during the night. This is believed to be due to the action of the sun upon the atmosphere, but I merely remark on this in passing.

In dealing with the subject of wireless telegraphy it is usual to commence by describing Sir William Preece's system, it having been first in the field, but as it is based upon quite a different principle from the systems at present in general use, I have purposely omitted it up to this point. Preece's system is based upon the fact that if a varying current of electricity is sent along a wire it will induce a similar current in a

wire placed parallel to it. It is only necessary to make and break the battery circuit in the transmitter, whereupon clicks will be heard in a telephone receiver attached to the distant parallel wire. It is found that if the distance between the two parallel wires is to be increased there must also be made a corresponding increase in the length of the wires. This has a decided limiting effect, for if we wish to send a wireless message across a gulf five miles in width we must erect two parallel wires each measuring about five miles. Here is a difficulty which cannot for the present be overcome, and unless some means of dispensing with the long stretch of wire is found, Preece's system can only be of service in special cases. If instead of a long stretch of wire we try the same wire coiled up, the effect is not the same. Of course, the long parallel wires are earthed at their two ends.

Preece's system is in use between Rathlin Island and Ballycastle, on the north coast of Ireland, a distance of about eight miles. Another installation is of special interest, as speech is transmitted by wireless telephony in this instance. This is over a distance of three miles, the one station being on one of the rocky islets known as the Skerries, and the other on Holyhead Island.

At present there does not seem to be much hope of wireless telephony on a commercial scale, as the selective difficulty is very much greater than is the case in wireless telegraphy. Some companies, however, undertake the installation of wireless telephone stations up to a distance of one hundred miles.

One sometimes sees in the daily papers such head-

lines as "Boat driven by wireless telegraphy," but these are rather misleading. The source of power is really stored up on the boat, and is merely controlled by a coherer operated from a distant transmitting station by the electric waves. The great Austrian electrician, Nikola Tesla, has prophesied the transmission of power without connecting wires, and he has devised many interesting experiments in America, but the practical outcome is still in the future.

By permission of *Popular Electricity (Magazine)*

An Electric Elevator for Ocean Liners

The men loading the vessel merely lay down the bags and boxes upon the gangway, and electricity does the rest. A small electric motor keeps an endless platform in motion, so that any goods laid upon it are carried on to the ship.

CHAPTER XVI

ELECTRICAL TRANSMISSION OF SPEECH

The air is a poor conductor of sound—Making a distant iron rod produce a musical note—How the modern telephone works—What a vibrating plate really means—Interesting experiments—How a large telephone exchange is worked—Finding out if a subscriber is already engaged

WHEREVER did man get the idea of transmitting speech by electricity? When it was once known that an electro-magnet could be made to attract and let go a piece of iron, the idea of using this for making signals was a very natural thought, but to think of electricity transmitting actual speech is quite another matter.

Man had long recognised that air was not the only conductor of sound, and that it was indeed a very poor conductor when compared with water or metal. The speed at which sound travels through water was carefully determined by experiments made, in 1826, in the Lake of Geneva. An ordinary bell when sounded under water could be heard at a distance of eight or nine miles by placing a large ear-trumpet in the water at the distant place. It has been suggested of late years to make use of such an arrangement for communication between ships, but the reason for referring to the matter here is merely to make it quite clear that man had definite

knowledge of the propagation of sound through water. It was then quite natural to test the velocity of sound through solids, and it was determined that sound would travel fifteen times quicker through steel than it would through air. This gave rise to the scientific toy called the string telephone, and later to a practical telephone which was entirely mechanical, and consisted of a steel wire tightly stretched from one sounding disc to another. I remember seeing telephones of this class in use in public works, for communicating from one building to another. The distance over which such telephones can be used is very limited, for the energy of the sound is very quickly dissipated in moving the molecules of the steel wire.

Suppose for a moment that it was possible to send sound over a long wire, say from London to Edinburgh, and you were going to speak to a friend at the distant end of the wire. You would have finished several sentences before the first word reached your friend, and after you had left off speaking the listener would still hear your voice for two minutes more. Although it was found to be quite an impossibility to transmit sound so far, yet man had the idea of conveying speech from one place to another by means of a metal wire. How did he come to think of electricity as a possible carrier? The idea arose in this way. An American physicist was experimenting with some magnets when he discovered that if a piece of iron rod was quickly magnetised and demagnetised, it emitted a distinct musical sound. It was therefore possible to make a piece of iron at a distance emit a sound, by sending an electric

current along a connecting wire, the wire also passing around the iron rod. This, however, was merely making the distant iron rod sound out a note such as might be produced by striking the rod on one end. More than twenty years elapsed before it was discovered that if the electric current was properly controlled any sound might be reproduced at the distant end of the wire.

The word telephone simply means an instrument for transmitting sound to a distance, but we now associate the word with the electrical transmission of speech. The telephone consists, like the telegraph, of two distinct parts, a transmitter and a receiver. The fundamental principle of the telephone is to control a battery current by means of sound vibrations and reproduce similar sound vibrations at a distant place. At first only musical sounds could be transmitted, and even when Sir William Thomson (Lord Kelvin) introduced Graham Bell's speaking telephone to the British Association meeting in Glasgow in 1876, it was looked upon more as a scientific toy than a thing of practical use.

Twenty years previous to this a French scientist had written a paper containing a remarkable and definite proposal of an electric telephone for the transmission of speech over great distances. In this interesting paper Mons. Charles Bourseul said: "I have asked myself whether speech itself may not be transmitted by electricity; in a word, if what is spoken in Vienna may not be heard in Paris. The thing is practicable in this way:—We know that sounds are made by vibrations, and are adapted to the ear by the same vibrations which are reproduced by the

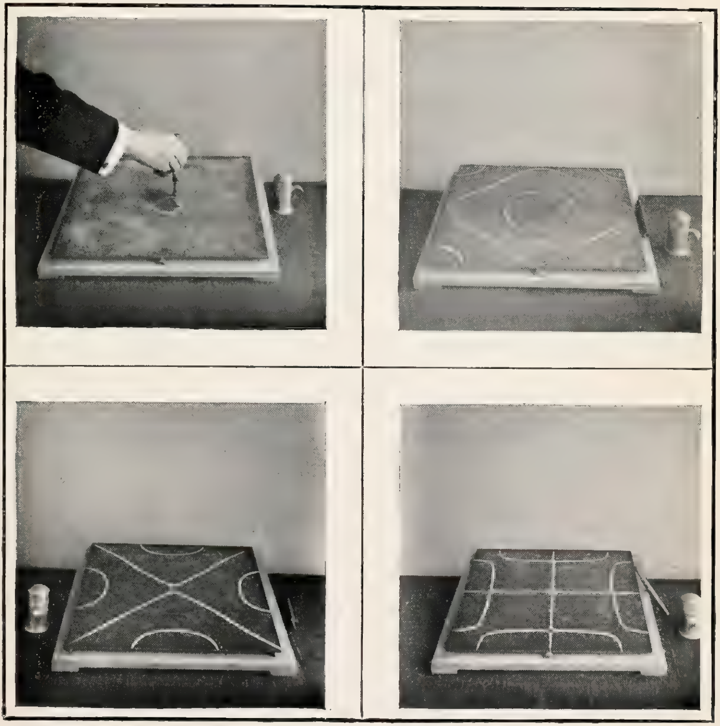
intervening medium. . . . Suppose that a man speaks near a movable disc, sufficiently flexible to lose none of the vibrations of the voice, that this disc alternately makes and breaks the current from a battery; you may have at a distance another disc, which will simultaneously execute the same vibrations. . . . I have made some experiments in this direction; they are delicate and demand time and patience, but the approximations obtained promise a favourable result." This was not only a remarkable prophecy, but a definite suggestion of the principle upon which all telephones have since been constructed. The scientific world at that time thought this merely a fanciful dream. It was indeed the very germ of a great invention.

In order to simplify matters I shall not describe any of the earlier telephones, but pass on to the telephone of to-day. I shall presume that the reader only desires to know how the telephone works, without learning all the details of wiring, &c. In the transmitter, or speaking part, there is a small circular disc of metal about the same thickness as the leaves of this book. This metal plate, or diaphragm, will vibrate under the influence of ordinary speech, while in the receiver, or hearing part of the instrument, there is a similar metal diaphragm, which may be caused to vibrate in exact unison with the distant speaking disc. In the old string telephone the two discs vibrated in sympathy with each other, because a tightly stretched string or wire conducted the vibrations from the one disc to the other. In the modern telephone the speaking disc controls an electric current, and the resulting current arriving

at the distant receiver controls the other disc. When the speaker lifts the telephone receiver off its hook or support a battery current is automatically switched on to the line wire connecting his telephone to the distant one. This current on reaching the distant receiver passes round a small electro-magnet, in front of which is placed the thin sheet-iron disc. As long as a steady current flows around the electro-magnet it merely produces a steady attractive pull on the iron disc, and there is therefore no vibration. If, however, the current is made to vary, then the disc vibrates, under the varying magnetic force, and a humming sound is produced. It only remains to control these vibrations by controlling the current from the distant end of the wire. In the distant transmitter the battery current has to pass through a small box of finely granulated carbon before reaching the line wire. In passing through the carbon the current meets with considerable resistance, because of the innumerable loose contacts through which it has to make its way. If these particles of carbon are pressed more firmly together, it is natural that the current can then more easily get through from one to the other. It is therefore arranged that the speaker speaks against a thin metal disc which forms one side of the box containing the carbon, and as this disc vibrates in sympathy with the speaker's voice, it controls the battery current passing through the carbon powder. We therefore have an ever varying electric current passing along the line wire, and when it reaches the distant station it energises the electro-magnet in the receiver and sets up vibrations in the metal disc, which the person

at that end has placed close to his ear. This little disc exactly imitates the one at the sending station; and as the sending disc is moving with the air vibrations representing speech, so the receiving disc again sets up these air vibrations which, when interpreted by the listener's sense of hearing, are recognised as speech. Undoubtedly the most remarkable thing about the telephone is that a flat metal disc can give to the air the same complexity of vibrations as we do with the aid of all our human speaking apparatus. So "true to life" are the vibrations reproduced, that we may easily recognise even the tone of a friend's voice.

Be it noted that these vibrations given to the metal disc are not simply to-and-fro movements of the disc itself, but they are vibrations of the molecules composing the disc. In order to demonstrate this fact, which is too often ignored, I have photographed three different effects produced by a large metal plate when vibrated at different rates. This method of demonstration was discovered by the great German physicist Chladni about a century ago. Chladni's method was to support a light plate at its centre, it being firmly screwed on to the top of an upright pillar. In the accompanying photographs a heavy iron plate, weighing about fifteen pounds, has been used. This plate merely rests on four rubber supports, and the positions of these may be changed at will. This is a much more convenient form of a Chladni plate. In order to show what happens in a vibrating plate, sand is sprinkled all over its surface. When the plate is vibrated the sand immediately commences to dance vigorously upon the plate, and soon takes



1 2 3 4

DESIGNS PRODUCED BY A VIBRATING PLATE

The first illustration shows the method of vibrating the plate after sprinkling it over with dry sand. The other three photographs show how intricate are the vibrations of a metal plate. This is of interest in connexion with telephones.

(See chap. xvi.)

up a definite series of positions, producing a symmetrical design. The reason for this is that the molecules in some parts of the plate are vibrating in the opposite direction to those in other parts, so that there is a neutral or nodal line between such parts. The sand is therefore shaken off the vibrating places to those dead lines. Perhaps the nodal lines, or nodes, will be better understood by reference to a stringed instrument such as the violin. The nodes or points of rest in a violin string are, of course, at the bridge of the instrument and at the point held down by the player's finger.

In the accompanying photographs Fig. 1 shows the large iron plate covered with sand and in position to be vibrated. The vibrator, or generator, consists of a short wooden rod with a leather tip, such as is used on a billiard cue. This little wooden rod is firmly fixed in a suitable metal handle. This generator is then gently drawn across a small area of the plate, whereupon a faint musical note will be heard, and by gradually increasing the strength of the stroke the plate is soon made to emit a loud note. The note produced will be a true indication of the rate at which the plate is vibrating. The quicker the vibrations, the higher will the pitch of the note be. The second photograph (Fig. 2) was taken after causing the plate to vibrate at about twelve hundred vibrations per second. Fig. 3 shows the effect produced when the plate vibrates at the rate of ten hundred and sixty vibrations per second. The rubber rests have been left in the same position as in Fig. 2, and the same generator or vibrator has been used. How, then, does a different figure

appear? When one gently draws the vibrator across the plate there will probably be three different notes at first discernible, and one has just to try and coax the particular note desired to come to the front, as it were, and gradually the plate is caused to sing out clearly the one note aimed at. Every time a particular note is sounded its own particular figure or design appears. The fourth photograph (Fig. 4) is the result of the plate vibrating at about eleven hundred and twenty-five vibrations per second. This figure is produced by the same vibrator, but it has been necessary to alter the position of the rubber supports. For the two previous figures the rests were placed at the centre of the sides, but in this figure (Fig. 4) it will be noticed that those parts of the plate are to be in vibration, so that the rests must be moved over to some points that are going to be nodes or dead points. A great variety of different figures may be produced by this plate; but in order to get notes a good deal lower than those already spoken of, it is found necessary to use heavier vibrators.

These figures result from the molecular vibrations of the plate; they seem very complex, but they are comparatively simple, being produced by one definite rate of vibration. The telephone disc has a much more difficult task, for it has to respond to all the intricate vibrations represented by the complexity of speech. These experiments with the vibrating plate will, however, enable us in some measure to appreciate the intricate vibratory motion given to the metal diaphragm in a telephone instrument.

We now picture the diaphragm in the transmitter

performing a myriad of ever changing vibrations, while the electric current under its control is varying in a corresponding manner, and at the distant end is causing the receiving disc to imitate the vibrations of the transmitter disc. In this connection I would suggest the following experiment. Taking two large metal plates the same as the one shown in the accompanying photographs, we arrange them at some distance from each other—say, at the opposite ends of a long lecture table. The plates might be placed in separate rooms, or even in different towns far distant from each other, but for the purpose of demonstration it would be more suitable to have them in the same room. We arrange that the vibrations of the one plate shall control a battery current passing along a wire to an electro-magnet placed under the second plate. We now sprinkle sand upon both plates, and when we vibrate the one plate as before, the second one will be set into motion by the electro-magnet, so that the sand figure will not only appear on the plate vibrated by hand, but will also appear upon the second plate. We may now imagine the plates separated many miles from each other, and the figure may be thus reproduced at the distant end of the connecting wire. Here we have an electric telephone, only our metal plates are too heavy to respond to the delicate and complex vibrations of the voice.

It is quite evident that no sound passes along the wire, but merely an electric current controlled by sound at the one end, and reproducing sound at the other end. It has already been pointed out that if it was possible to transmit sound along a wire to a

great distance, the speed of travel would be very slow. If speaking from New York to Chicago, a distance of over one thousand miles, the speaker would have commenced his conversation about five minutes before the listener could hear any sound.

A pair of telephone instruments permanently connected together provide communication between two definite places, but it was early recognised that if a person in one part of a city could speak to any other person in the city who had a telephone, then it would be a much greater advantage. This was easily arranged, for it only meant bringing all the telephone wires to one central office or exchange, where any two wires might be connected together temporarily. As the telephone instruments and lines are rented annually from the Telephone Company, the parties thus hiring the telephones are called the subscribers. All the subscribers' telephone wires therefore terminate at the exchange. A very convenient way of making a temporary connection between one wire and another is to fasten a metal plug to the one wire and a metal socket on to the other wire, such as the movable plugs used in houses for connecting portable electric lamps, &c., to the electric mains. As it is necessary to be able to connect any two of the telephone wires together, it is more convenient to fix a socket to the end of every wire, and then use a short length of flexible wire, having a plug at each end. By placing one plug into the socket of one telephone wire and the other plug into the socket of another subscriber's wire, these two subscribers' telephones are then directly connected through to each other. As tele-

phones are now arranged with a return wire instead of using an earth connection as in the telegraph, it is necessary to carry two wires from each instrument. There are therefore two wires fixed to the socket, each wire being insulated from the other. The plugs and the flexible cords are similarly arranged with two separate wires, and when the plugs are inserted in the sockets, the pair of wires are connected in such a way that there is a complete metallic circuit from the one telephone instrument to the other and back again. One wire only was at first used, the ends being earthed; but it was found that the current in one overhead wire was apt to set up or induce a similar current in a neighbouring wire, and this was more easily got rid of by making a complete metallic circuit. To simplify the description of the telephone exchange as much as possible, it is well to think only of one wire connecting the two telephones together.

The operator at the exchange may easily connect any two subscribers together, but every subscriber must be able to communicate with the operator and inform her of the number he desires to speak to. Each subscriber, of course, has a number given him, these numbers being stated in a telephone directory. If there were only a very few subscribers, say, from fifty to a hundred altogether, then one operator could attend to them all and make the necessary connections and disconnections. In some exchanges, however, there are as many as from five to ten thousand subscribers' lines to look after; it is therefore necessary to have a large number of operators. Each operator will have from sixty to eighty subscribers to attend to, but she must be able to connect these subscribers

with any other number in the whole exchange. The ends of all the wires are fastened off in small sockets arranged on a table or upright board in front of her. She can easily reach any part of this board without rising from her seat, as the sockets are made small and are very compactly arranged. This operator may therefore, by taking a flexible wire and two plugs, connect any two of these sockets together. She will, however, find her time well occupied in attending to the requests of the eighty subscribers who may communicate with her and ask her for any other subscriber in the exchange. All the sockets in the board are, of course, numbered, but when the operator receives a call from one of her eighty subscribers, whose number may be 1563, it will necessitate her locating that number before she can get in connection with him to ask him what number he desires. It is therefore more convenient to arrange eighty other special sockets close beside the operator, and to carry a branch line from No. 1563 and her other subscribers to these sockets. These are termed the "answering jacks," the word jack or spring-jack being given to the small sockets. Each of an operator's eighty subscribers has therefore an answer jack in addition to the ordinary jack, and it will be more convenient to connect the flexible wire from one of these answering jacks to the number called for in the board. How is the operator to know when one of her subscribers desires to speak to her? There is a tiny electric lamp placed immediately under each of these answering jacks, and when the distant subscriber desires to call the operator's attention he lifts down his telephone off its support,

and then depresses a push-button, which causes the tiny lamp opposite his answering jack to light up. In some cases it is arranged that the lifting of the telephone itself switches on the lamp, thus saving the subscriber the trouble of pressing the push-button. When the operator sees the lamp light up she places one end of a flexible wire into the answering jack, and by means of a small lever she can temporarily connect this wire to her own telephone instrument, the receiver of which is always to her ear. As soon as she learns the number of the subscriber wanted she switches off her own instrument and places the other end of the flexible wire into the jack or socket of the number called for. The calling subscriber is now directly connected through to his friend, with whom he may converse. When he has finished his conversation and desires to have his telephone disconnected, how is he to call the operator's attention? This is very simply arranged. When she made the connection with the calling subscriber's answering jack the signal lamp went out, but there is another lamp which represents the flexible wire. This lamp is not lighted during the conversation, not until the subscriber again depresses his push-button, whereupon this second signal lamp glows, and the operator knows that she may remove the flexible wire which was used in making the connection. It is sometimes arranged that, when the subscribers both place their telephones back upon their hooks or supports, this signal lamp is automatically switched on. This automatic arrangement is good, for otherwise it often happens that a subscriber forgets to call off when finished, so that he is

believed to be engaged when he may have finished some time previously.

We now see how one operator is able to connect eighty subscribers to any other subscriber they desire, but what about the thousands of other subscribers? There is nothing for it but to have another operator for every eighty subscribers. It is clear that they cannot all sit in front of the board just described. Only three operators can work at this board without being much in each other's way, so it will be necessary to have another duplicate board for every three operators. The whole board is therefore called a multiple switchboard. Branch lines are run from each socket in the first board to similar sockets in the next board, or perhaps a better mental picture is to think of one subscriber's telephone line coming in to the exchange and passing right along through all the boards, being merely tapped at each board by a socket, just as one might have a number of water taps on one length of pipe. Each operator may now connect any of her eighty calling subscribers with any other subscriber, but here arises a difficulty. How is she to know that no other operator has already connected some one else to the number she is asked for? Smith speaks to his operator at the first table and asks by number for Jones, and while they are speaking Brown asks his operator, who is at a different table, to connect him to Jones. What is to prevent the second operator from connecting Brown to Jones, although he is already speaking to Smith? Fortunately the operator can at once tell whether or not the line called for is already engaged. Before inserting the connecting plug she touches a small metal ring at the

mouth of the jack or socket of the number called for, and if she hears a loud click in her telephone she knows that the line is engaged, and she at once informs the calling subscriber of this fact. This click may be heard any day at an ordinary telephone by depressing the telephone hook or support while holding the telephone to the ear. This cuts off the battery current, and a click will be again heard when the telephone support is allowed to spring up, thus switching on the current. This click is due to the sudden making or breaking of the battery circuit. The little rings at the entrance to the sockets of one subscriber are all connected together by a wire, but this wire is insulated, or, in other words, it leads to nowhere, so that when the operator touches one of these rings with the wire from her own telephone no current will pass, and there is therefore no click. If, however, any one of the jacks belonging to one subscriber is in use, the plug in it causes this insulated wire to be connected to earth, so that if any other operator now touches one of the jacks or sockets belonging to this number she will at once hear a click in her telephone, as her battery current will get to earth. She therefore makes no further connection, but informs the calling subscriber that the number he asked for is already engaged.

The wiring of a telephone exchange is a most complex subject, and there are many points of interest which cannot be touched upon here, such as the test room, the mechanism for operating the signal lamps, &c. &c. Then there are other systems of communicating with the operators, but the one described will be sufficient to show how a modern exchange is worked.

CHAPTER XVII

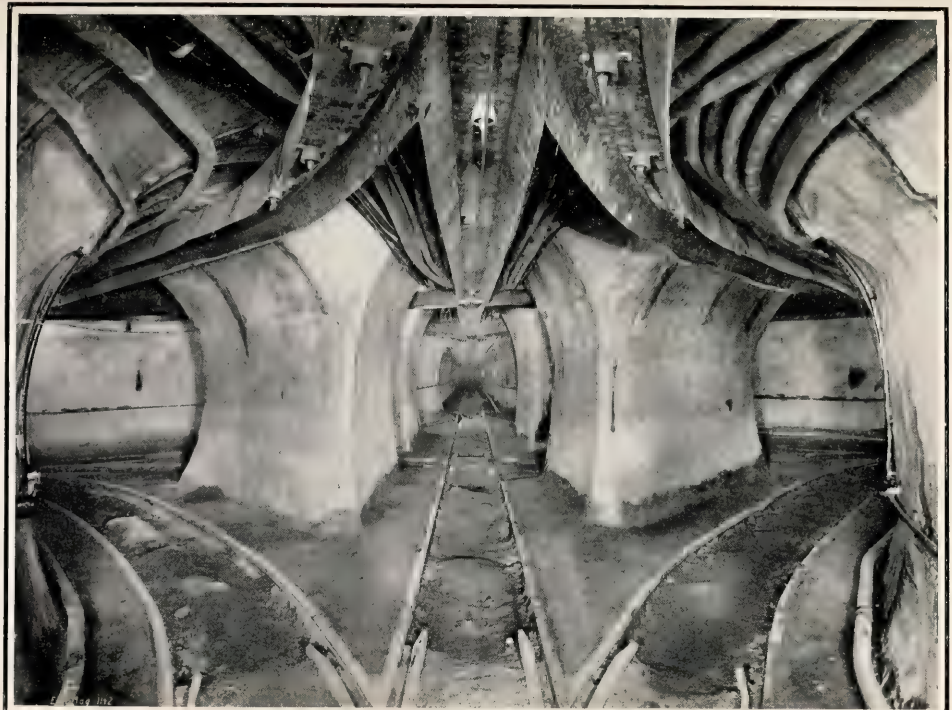
MORE ABOUT TELEPHONES

Automatically selecting a disengaged operator—An exchange without any operators—Submarine telephones and their difficulties—Trunk lines—A very honest automatic machine—An old wireless telephone—Odd applications of the telephone—"Seeing by telephone"

THERE are some modern developments of telephone exchange working which are of so much general interest that they cannot be passed over, although they form too large a subject to be dealt with here in detail. There is one difficulty which it might seem impossible to overcome. It is only natural that some subscribers request many more connections to be made for them than others have occasion to ask. Then, again, some subscribers happen to use their telephones more at one hour of the day than another, so that one operator may have more connections than she can very well attend to, while other operators at the same moment have very few calls. A most ingenious method has been devised to obviate this difficulty. In a shop or store any assistant who is free attends to a purchaser. Could this same principle be carried out in a telephone exchange? It can be done by a mechanical automaton selecting a free operator for the subscriber. In this case the operators have no definite set of subscribers to attend to. When the subscriber lifts

his telephone off the hook he causes an electric current to operate a little electro-magnetic device known as a selector, and this instrument switches his line wire on to the first operator who has a flexible cord disengaged. The current then lights a small signal lamp opposite the flexible cord, and the operator at once connects up her telephone and asks what number is desired. She does not require to know who is asking for the number, for if she connects this flexible wire to the number asked for, then the subscriber, whoever he is, has got through to the subscriber he desired to speak to. In this way an operator is kept busy attending to any one who happens to call while she is free, but she is never overcrowded with work, for no one can signal to her while her connecting cords are all engaged. When the subscribers have finished their conversation they merely lay their telephones down again upon the hooks or supports, and this act automatically disconnects the subscribers, for it causes the selector to free the subscriber's line from the connection it made to an operator. At the same time a signal lamp tells the operator that the particular connecting wire used is now free, so she withdraws the plug from the jack or socket in the multiple board. Not only does this ingenious method prevent any operator being asked to attend to a call unless she is free to do so, but it also ensures a subscriber being attended to by some one immediately he lifts his telephone off the hook. What more can we expect than this? We may demand that the automatic selector should find the number we desire and then connect us to it. This seems

rather a large order, but nevertheless it has been successfully accomplished. There are several very large telephone exchanges in America, and some smaller installations in Europe, in which the operator's services have been entirely dispensed with. The subscriber merely moves a dial on his instrument to each consecutive figure of the number desired, letting the dial spring back to its normal position between each figure. Each particular movement means a certain number of electric impulses sent out to the selector at the exchange, and this ingenious electro-magnetic device switches the subscriber's line wire to the line wire of the number thus signalled. The first figure signalled by the dial selects the particular thousand in which the desired number is, then the particular hundred, then the ten, and finally the unit. If a subscriber should by means of his selector switch his line on to a number which is already engaged at another selector, then he hears a buzzing sound in his telephone, and his selector releases his wire, allowing it to drop back to normal. If, however, the number desired is free his selector switches his line on and allows it to remain there until the subscriber places his telephone back on its hook, whereupon the selector automatically releases his line wire and leaves it ready for another call. I have seen some very satisfactory reports by subscribers to these large automatic exchanges in the United States, but it remains to be seen whether the purely automatic or the semi-automatic system will become the system of the future. With so many able electricians at work upon the problem of telephone exchanges, there is no doubt that many



By permission of *The Electrical Magazine*

In a network of small tunnels under the streets of Chicago electric goods-express trains help to relieve the overhead traffic. The current is got from an overhead wire immediately over the track. The heavy cables on the roof contain the wires of the Automatic Telephone Exchange.

advances will be made which we do not at present foresee.

One can not only speak by telephone to any part of a large city, but to other far-distant cities, and even from Great Britain to different parts of the continent of Europe. The Londoner may converse with the Parisian although separated from each other by a long stretch of land and sea. The extent of the sea to be spanned is the main factor in determining the possible distance to which one may speak. As long as telephones are connected by bare overhead wires, conversation may be quite conveniently carried on over a distance of a thousand miles and more, but when it is necessary to enclose the wire in an insulated cable, whether placed under the ground or sea or not, it is quite a different matter. The greatest expanse of sea that has been successfully spanned so far will not exceed fifty miles. A simple relay or repeater such as is used with telegraph instruments is of no use for a telephone. The telegraph current is a make and break arrangement, whereas the telephone current is a much more delicate and ever-varying or undulatory current. Can nothing be done to intensify the telephone current ? Every telephone current is intensified before it leaves the transmitter, by passing through an induction coil, the principle of which will be explained in the following chapter. It is not very convenient, however, to introduce induction coils inside a submarine cable. Some interesting experiments have been made by the electricians of the British Post Office with a long stretch of cable on land. A cable which could only carry speech a distance of sixty-six miles was so

improved by the introduction of an induction coil at every mile, that when thus arranged it was possible to converse through one hundred and seventy-six miles of the same cable. We still await some practical method whereby a cable may be made to carry telephone currents across the Atlantic.

It is not easy for the layman to grasp the full meaning of this difficulty in transmitting a telephone current through a long insulated cable. This difficulty has already been referred to in the closing sentences of chapter xiv., but the trouble is increased when instead of the telegraph current we substitute the delicate telephone current. The trouble is due to the fact that when an electric current passes along a cable there is not only the effect produced in the conductor, but also in the neighbourhood surrounding the wire. We may picture the current in the wire setting up or inducing another current or electric charge in the sheathing of the cable or in the surrounding surface of the sea-water itself. This induced charge attracts the current being sent along the wire and thus retards it, so that it is partly dissipated and arrives in a very much weakened condition. Perhaps a more correct mental picture, though not so picturesque, is to think of the moving current setting up an electro-magnetic disturbance in the ether around the cable, and it is clear that in so doing it must expend some of its initial energy. This troublesome property of a cable is called its inductance, and while this may be balanced to a certain extent for a telegraph current by adding condensers at either end of the cable, this will not avail in connection with delicate telephone currents operating

sensitive instruments. When a submarine telegraph cable is connected to condensers the cable is not directly earthed. It is just as though the cable was connected to a metal plate at each end and left insulated from the earth, but another plate is placed very near to the first plate and this second plate is connected to earth. With an arrangement of this kind it is found that the signals are very much improved, so that as far as telegraphy is concerned the difficulty has been overcome and the signals kept quite clear of each other. It is only reasonable to suppose, however, that the telephone current which we may picture as a gentle ripple of waves, in contradistinction to the telegraph splash, is more easily affected by the retarding effect, so that the controlling current becomes distorted and quickly dissipated.

The long-distance telephone lines connecting distant towns together are called trunk lines, and the transmitting power of these is so good that sometimes when one is conversing with a man distant many hundreds of miles, it is difficult to realise that he is not really quite close at hand. Here is a man sitting at his office desk, and he wishes to speak to another business man who is in a far-distant town. Without rising from his office chair he can take down his telephone and inform the operator of the town and subscriber's number he desires, and in a few moments he is speaking to his friend. He is able to carry on a conversation just as though he had been bodily transported to the distant town.

Public telephone call offices or boxes may be found in every district of important towns. There is a very

ingenious arrangement of call-box in some Continental towns, and these deserve special mention as they are different from many "penny-in-the-slot" machines, in that they are thoroughly honest. The usual method of working a public call-office is that the person first signals to the operator, and when she has called the subscriber desired, she requests the person calling to insert a penny in a money-box and then turns a handle. This causes a sound to be made in her telephone, and she then gives the desired connection. In the Continental call-office the speaker cannot signal the exchange until he has placed his coin in the money-box, so that the operator is free from the superintendence of the necessary payment, and she can proceed at once to make the desired connection. If the operator finds that the number asked for is already engaged, she intimates this fact to the caller, and he can depress a push on the money-box, whereupon his coin will fall down into an open drawer. When the number requested is free, the operator at once makes the connection, and this causes the coin to fall into another department in the money-box, from which it cannot be withdrawn. If, however, the person inserts a wrong coin in error, say a smaller silver coin, the machine will not accept it, but allows it to fall into the open drawer. This is easily managed by arranging that the coin passes over a slot, just made small enough to prevent the correct coin slipping through, but any smaller coin in attempting to pass over the slot falls through into the open drawer. The money-box is therefore as honest as can be desired. It only wants a means now of giving back the correct change to any one

not happening to have the required coin at the moment.

The subject of wireless telephony has been briefly dealt with in chapter xv., but it may be of interest to remark here that a wireless telephone existed long before any wireless telegraph experiments were made. Very shortly after the invention of the telephone it was discovered that speech might be transmitted along a beam of light. The disc or diaphragm of the transmitter was a thin plate of silvered glass or mica, forming a flexible mirror. A powerful beam of light, electric or sun light, was thrown upon this little mirror, and from there it was reflected to a distance, first of all passing through a lens which focussed the light into a beam of parallel rays. This beam of light fell upon the distant receiving apparatus, in which was placed a piece of the very peculiar metal selenium. The peculiarity of selenium is that its resistance to the passage of an electric current through it is greatly diminished when exposed to the light. It is most sensitive to light, and its resistance immediately varies with every change of light falling upon it. Hence when the little flexible mirror diaphragm is made to vibrate by the speaker's voice it alters the light falling upon the distant selenium receiver, and this controls a battery current passing through a telephone receiver. In this way the movements of the transmitting disc, the mirror, are imitated by the disc in the telephone receiver, and the speech is reproduced. This is true wireless telephony, and has been employed in speaking from shore to ferry-boats, &c., but it is quite apparent that the possible distance is limited. How very

similar this is to the present system of wireless telegraphy. The selenium receiver is very like a coherer in its action. It is acting as a broken bridge to the local battery current till the ether disturbance falling upon it reduces its resistance and enables the current to pass. One sometimes reads of this wireless telephone as though it was a new discovery, but, as already stated, it is almost as old as the telephone itself. This wireless apparatus was at first called a photophone, and later a radiophone.

In closing this chapter it may be mentioned that although the telephone's value lies essentially in its power of reproducing speech, it also proves useful for other purposes. It has been used in naval operations for detecting the whereabouts of torpedoes, and it has also been adapted as a deep-sea sounder. Specially arranged telephones have been used to detect watered wines, to distinguish false from genuine coins, and as a "diviner" to locate iron ore in the earth if near the surface. In chapter xv. we have seen how the telephone receiver makes a useful "sounder" in wireless telegraphy, and in chapter xiii. a multiplex telegraph is described, in which telephone receivers hum out the clicks of the Morse code.

When one hears of a telephone instrument which can receive a message in its owner's absence and deliver it to him on his return, which is an accomplished fact, one feels inclined to speculate what the business offices of our great-grandchildren will be like. How many more automatic devices will they have in their service? Would any of our

great-grandfathers have believed that their near descendants would be about to speak to each other across a distance which to them meant a journey of many days?

Every now and again we read announcements of the invention of an instrument by which one may see what is happening at a great distance away. It is a common practice to head such paragraphs, even in scientific journals, "seeing by telephone," but this is surely a misnomer. There is no sound (*phone*) connected with the subject, and it would be better to say "seeing by telegraph" (*grapho*, I write), although that too would be clumsy. We already have the word telescope (*tele*, a distance, and *skopeo*, I view), but no doubt a suitable word will be forthcoming if it ever becomes possible to electrically reproduce at a distance the complex ether disturbances which give rise to the sensation of vision.

CHAPTER XVIII

SOME INTERESTING EXPERIMENTS

A remarkable experiment by the late Lord Armstrong—How the experiment failed when attempted in public, but was successfully performed again fifty years later—The famous Spottiswoode coil—Wonderful performance of an electric spark—Curious experiment with an egg-shell in a magnetic field—The autograph of an electric spark—An erroneous idea regarding some effects of lightning upon the human body

We might say that every electrical experiment has a mysterious interest, but it is only intended to mention, in this chapter, a few of the more remarkable.

An experiment which was shown by the late Lord Armstrong to the Philosophical Society of Newcastle-upon-Tyne in 1893, has always seemed to me to be of more than passing interest. About fifty years previously Lord Armstrong had exhibited his hydro-electric machine to the same Society. The interest evinced on that occasion was so great that when his lordship arrived at the lecture hall, both it and the passages were so crowded that he had to enter in burglar fashion, climbing in by a window. Shortly after the discovery of the hydro-electric machine, he made a very large one which he presented to the London Polytechnic Institution. This machine proved to be by far the most powerful instrument for the production of frictional electricity that had ever been seen. Lord Armstrong only had

the machine in his hands for a short time after its completion before handing it over to the Institution, but he made many interesting experiments during the time he had it.

Among other experiments he hit upon a very remarkable one. He took two wine-glasses filled to the brim with chemically pure water, and he connected the two glasses by a cotton thread coiled up in one glass and having its shorter end dipped into the other glass. He then made a connection from one terminal of the large hydro-electric machine to the one glass of water, and placed another conductor from the other terminal of the machine to the second wine-glass. On turning on the electric current, the coiled thread was rapidly drawn out of the glass containing it, and the whole thread deposited in the other, leaving, for a few seconds, a rope of water suspended between the lips of the two glasses. Lord Armstrong attributed this effect to the existence of two water currents flowing in opposite directions and representing opposite electric currents, of which the one flowed within the other and carried the cotton thread with it.

Lord Armstrong had only performed this experiment with the very large machine which he built for the London Polytechnic, and it so happened that he had made the experiment out of doors. It was found later that the machine would not give the same power when fitted up indoors in London, probably because the insulation obtained indoors was not so perfect. It must have been very disappointing to the inventor when he failed in reproducing this experiment publicly in London, after it had been announced that he would

do so. However, at the Newcastle Philosophical meeting of 1893, which was about fifty years later, Lord Armstrong determined to reproduce the wine-glass experiment, or an equivalent one, by using a large induction coil in place of his early hydro-electric machine.

By arranging a glass bulb and cistern so that they could be placed in the field of the lantern and exhibited on the screen, Lord Armstrong was able to show a spongy cotton thread climb up out of the cistern into the bulb, and when the current was reversed the thread climbed down again. It was quite apparent that there was a flow of water in the opposite direction to that in which the cotton thread travelled. When the coil of cotton thread left the bulb it might have been expected that the level of water in the bulb would be found to have been lowered, but the level remained the same as before, proving that water had travelled from the cistern to the bulb in the opposite direction to the cotton thread. There therefore appeared to be one current within another flowing in opposite directions. If the cotton thread was prevented from travelling, the water still passed over and raised the level of the water in the glass from which the cotton would travel if free to move. The water really travels in both directions, but it passes more freely over the top of the thread than through it in the opposite direction.

There is an immense induction coil at the Royal Institution, London, with which many interesting experiments were made while the coil was in use.

This coil, which was made about thirty years ago by the late William Spottiswoode, of the well-known firm of printers, was able to produce an electric spark measuring forty-two inches in length. A block of quartz glass three inches in thickness would make an excellent insulator for all ordinary electrical purposes, and yet when this was placed in the path of a spark from this coil, the glass was pierced right through. It was no mere pin-hole. When one examines the glass it looks exactly as though the hole had been drilled through by some machine tool. When flint glass was used in these experiments the glass was usually fractured as well as pierced. I remember many years ago seeing a heavy glass tumbler broken by a powerful electric spark from some very large leyden jars.

There is a very curious experiment which one does not often see performed, as the electric current for it requires to be got from a three-phase dynamo. The meaning of this class of dynamo will be explained later. The apparatus is nothing but a fixed coil of wire suitably arranged for connecting to a three-phase dynamo, and is shown in the accompanying photograph (page 288). An egg has been "blown," and the shell covered with a thin deposit of metal, leaving it still very light in weight. In the photograph I have used an egg without this metallic coating, as the prepared egg would not have been clearly seen against the dark board to which the coil is fastened. The prepared egg is placed upon a glass tray to insulate it from the board. In one room we have this coil of wire with the egg lying within it, while the wires

from the coil lead to the dynamo-room. Whenever the electric current is turned on we see the egg begin to move round, and it is soon spinning so rapidly that it stands upright upon its end. The egg will remain spinning as long as the current passes through the surrounding coil. It is curious to watch it when the direction of the current is reversed in the coil. The egg immediately slackens speed, comes to rest for a moment, and then sets off spinning as before, but in the opposite direction. This strange experiment will be referred to again later.

Another interesting experiment may be performed with a large electro-magnet supplied with current from an alternating dynamo. If a straight magnet of this class be placed in an upright position, it is found that, when a single copper ring is held over the magnet, the ring is forcibly repelled upwards. If the ring be tethered to the table, but left free to rise some little distance above the magnet, it will then be held up above the magnet, ignoring the attraction of gravity, and appearing simply to float in the air.

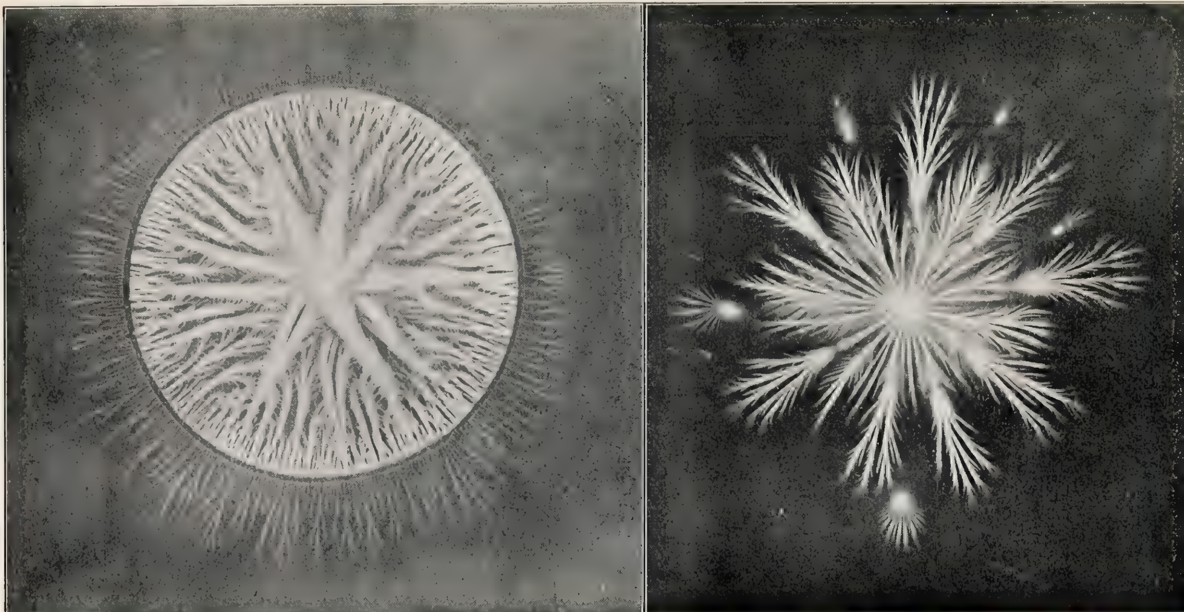
Many beautiful effects may be produced by high-tension electrical discharges. If fine tripoli powder is sprinkled on a glass plate and exposed to the spark from a large electrical machine, the dust figures thus produced are amazing in detail. What is perhaps of more interest from a pictorial point of view is the effect produced by the direct action of a spark upon a photographic plate. The accompanying photographs are the autographs of two electric sparks. These figures are due to the luminous effect of the sparks.

The duration of an electric spark is only a very small fraction of a second, and yet it can produce a wondrously intricate autograph. An electric spark appears to us to exist for quite an appreciable time, and so it does as far as our sensations are concerned. This is due to the image of the spark remaining on the retinas of our eyes after the source of light has been withdrawn. We are all aware that if a red-hot object be fastened to a string, and then swung rapidly round in a circle, there will appear to be a complete ring of light; but we know that the source of light is only at one particular point at one time. This persistence of vision, which makes the cinematograph a success, gives us a very false impression as to the duration of an electric spark.

The autographs of the electric spark shown in the accompanying illustration (page 270) were obtained by the late Lord Armstrong in the following manner. Two photographic plates placed back to back were used with the films on the outside. The upper side of the double plate carried a metallic ring about four inches in diameter, which served as the leading-in electrode from a very large electrical machine (Wimshurst). The leading-out electrode was merely a wire, the point of which was brought in contact with the lower side of the double plate at a point coincident with the centre of the ring. When a spark was allowed to pass from the ring on the upper plate to the point on the lower plate, the momentary luminous discharge produced the two figures shown in the illustration. When the plates were developed No. 1 figure was found upon the upper plate, and No. 2 figure upon the lower plate.

The figure reproduced in No. 1 seems to me of special interest, for it looks far more like the photograph of a solid creature than the impression of an electric spark upon a sensitised plate. To those accustomed to work with the microscope this figure will no doubt call to mind some transverse section of a spike of the Echinus (sea-urchin), or perhaps one of those marvellously constructed diatoms with which our lakes and seas abound. By varying the positions and forms of the electrodes, the late Lord Armstrong obtained a great variety of beautiful effects.

It may be remarked here that lightning has been known to leave its autograph upon the human body. Figures something similar to those shown in the accompanying photograph, but not so detailed, have sometimes been found upon the body of a person who has been struck by lightning. As these figures often have a tree-like appearance, or arborisation, an erroneous idea got abroad that the lightning had photographed part of some neighbouring tree upon the human skin. The same result could no doubt be obtained by the powerful spark from a large electrical machine, if any person was found foolish enough to make the experiment.

1  2

By permission of *Lord Armstrong*

THE AUTOGRAPH OF AN ELECTRIC SPARK

These beautiful figures were produced, by an electric spark, directly on to two photographic plates placed back to back.

(See chap. xviii.)

CHAPTER XIX

ELECTRICAL MEASUREMENTS

The meaning of measuring—How it is possible to measure electricity—The meaning of a volt—Analogies in connection with electric pressures—Interesting comparison between the rise of population in Johannesburg and the rise of electric pressures attained—The meaning of the ampere—The relation of volts to amperes—The value of the Watt—Measuring electrical resistance in ohms—The B.T.U. or Board of Trade unit—How much electric light one can get for a penny—Some other electrical units

To the layman it seems at first very strange to speak of measuring electricity, and he is somewhat surprised to learn that we can really measure this mysterious something with the greatest precision.

A discussion arises as to the relative size of two objects in a room, and as there is no measure at hand one member of the company takes a piece of string, and cuts it to the same length as one of the objects. He then informs his friends that the second object is nearly one and a half times as large as the first. It may be said that surely this is a very clumsy method of measuring, and yet it is just the principle we go upon in everyday life. If a foot-rule, an inch-tape, or a yard-stick had been at hand, the method of measuring would just have been the same. The measurer would merely have said that the one object was twice as long as his foot-rule, while the second object was nearly three times his foot-rule. He has

compared the objects with the length of his stick, and the only advance upon the string measure is that we have agreed that a stick of a certain length will be called a yard, and that one-third of that length will be called a foot, and so on. Our legislators have simply taken a bar of bronze and made two marks upon it, and then ordered that the distance between these marks shall be reckoned one yard. An inch is taken as one thirty-sixth part of that distance, and a mile as 1760 times the length of the standard bar from mark to mark.

We have artificial standards of length and weight locked up in safe keeping for reference, but the case is somewhat different with electricity. We construct standard electrical instruments which we use in practice, but these have not been based on any such artificial plan as adopted for length and weight. The units of electrical measurements have been scientifically determined, and can be reproduced at will; so that, while all our measuring of electricity in practice is done by comparing the effects produced on standard instruments, we do not require that our legislators should lock up any of these instruments for a standard reference. The scientist could reproduce them again at any time if required. This question of scientifically-determined units will become clearer as we proceed.

When the first Atlantic cables were laid, we had no standard electrical measurements. Electricians had made measuring instruments, but there were no definite units by which the effects might be reckoned. In the same way our early thermometers had no fixed scale. This want of any electrical units

was found very awkward. There was no use of one electrician reporting to another that the current required to be used "is such that it moves the indicator of my measuring instrument forty degrees." This value would depend altogether on the construction of the said instrument, and the particular way in which the scale of degrees had been divided. It was quite evident that if we were to make practical progress we should require some system of standard units of measurement. We might have gone upon the artificial plan of simply taking any one particular measuring instrument, and agreed that when the indicator of this instrument moved a certain distance, we should reckon that particular value as the unit. Our legislators would then have taken charge of this instrument, and allowed us to make duplicates, which could be standardised from the original instrument. A wiser plan was adopted.

The British Association, in 1861, appointed a committee of the foremost scientific men of the day, with Sir William Thomson (Lord Kelvin) as president, and the object of the committee was to suggest a suitable basis of electrical measurement. Many years elapsed before the final results were made public, but units of electrical measurement were determined upon purely scientific principles. These units were called the absolute units, the word absolute meaning that they were free from any particular conditions, or in other words, that they had reference to no artificial electrical standard, but could be scientifically reproduced at any time. The values of these absolute units will be referred to in a short note in the Appendix (page 339), for any readers who are anxious

to know something more of this subject. For the present we shall be content to know that these scientists arranged for us certain definite units of electrical measurement.

It so happened that the units thus scientifically determined were not of convenient size for measuring the currents we have to deal with in practice, and the committee therefore arranged a series of practical units, which are definite multiples or sub-multiples[1] of the absolute units.

If one is surprised that we can measure mysterious electricity, one should be equally surprised that we can measure radiant heat, for electricity and radiant heat are of the same nature. They are manifestations in the ether. The ether waves known as radiant heat strike upon a body and set up a molecular motion in the body. It is this molecular effect which we measure. Heat causes mercury to expand, and for the sake of comparison we use a scale of degrees suggested by Fahrenheit, or the centigrade scale of Celsius, while Germany uses a third scale, invented by Reaumur. Early thermometers had no definite scale. However, the point to be noted here is that we generally measure heat by its effect upon a column of mercury or spirits. In a similar fashion we measure electricity by its effect upon some material substance. There are several methods of doing this, but the most common is to note the electro-magnetic effect of the current.

If we have a single coil of wire with a small magnetic needle pivoted within its immediate neigh-

[1] While the word *multiple* is in common use, meaning a number which contains another an exact number of times, the word *sub-multiple* means a number which is contained in another a certain number of times.

bourhood, so that the magnet will be in the magnetic field set up by an electric current passing through the coil, we then have a means of measuring the current. The greater the current of electricity the stronger will the resulting magnetic field be, and the greater will be the turning movement of the magnetic needle. All such instruments are called galvanometers, and are in principle the same as the needle telegraph described in chapter xiii. (page 198). We have the magnetic needle and the coil of wire at the back of the dial, with an indicator on the face, the indicator moving along with the magnet. A scale of degrees is marked upon the dial so that the exact amount of movement of the indicator may be noted. In the simplest form of galvanometer the magnet is simply pulled against the force of gravity, the magnet falling to zero by its own weight. In the galvanometer we have a magnet moved by an electric current, while in the thermometer we have a column of mercury expanded by heat. Is the one phenomenon less wonderful than the other? We have become accustomed to the measuring of heat, and therefore it does not seem so strange.

This chapter is concerned with electrical measurements and not the means by which the measuring is done, so that this simple galvanometer will serve for the present merely as an indication of the general principle of measuring electricity.

If we have water flowing through a pipe we may measure the pressure exerted by the water, and this we state as being so many pounds to the square inch. When we have electricity flowing along a wire we may measure the electrical pressure, but we cannot

state this in any ordinary measures, and so we coin a word to represent a unit of electric pressure. The British Association, who arranged this unit for us, named it after the illustrious Italian, Professor Volta, who discovered the means of producing electricity by chemical process. The volt is a definite multiple of the absolute unit of pressure, which was scientifically determined, but the reader may form an idea of its value from the fact that the electric pressure at which any primary cell delivers its current is always between one and one and a half volts. The layman cannot hope to form any very definite conception of the values of electrical units if he never has occasion to use them. He would have no very definite idea of the value of a pound weight or a yard length unless he had some practice in the use of these.

The electrician does not often use the term electric pressure; he prefers to speak of it as electromotive force, and to save time writes it down E.M.F. He says that this electromotive force is due to a difference of electric condition or "potential" between the ends of the conductor in which the current is flowing, just as one might say that the pressure of water in a river is due to the difference of level of the two ends of the river. We therefore say that there is a certain difference of potential between the terminals of a battery or a dynamo. As to the nature of this difference of potential we have no idea. In the case of a river perhaps we are prone to imagine that we understand more than we really do. We certainly know that the pressure is due to the difference of level and we say that the water falls by gravity, but we have no idea as to the nature of this force. By

experiment we find that the potential or pressure of the current from a single chemical cell or "battery" is never more than from one to two volts. It varies according to the materials used in the construction of the cell. We may make the cell as large as we like, and therefore obtain a greater current, but we can never increase its pressure or electromotive force. A barrel of water twenty feet above sea-level is at the same pressure as a lake at the same level. While we cannot increase the electric pressure by enlarging the cell, we may add the pressure of a number of cells together by connecting the carbon of one cell to the zinc of the next cell and so on. In this way we may form a battery of any desired voltage by increasing the number of cells. If, instead of connecting the cells in "series" as described, we were to connect all the carbons of the cells together and all the zincs together, that is to say, carbon to carbon and zinc to zinc, we should not have increased the pressure, for the result would be just the same as though we had made one large cell. If we had a number of barrels of water and we placed them all at the same level, say, two feet above the ground, we should find on connecting them together by pipes that the pressure remained the same as we might get from one single tube, but if we placed each barrel two feet above its neighbour, then we should increase the pressure in proportion to the number of barrels connected together. This somewhat crude analogy may serve to clear up a point which I have found to be a stumbling-block to many.

Dynamos may be constructed to give any desired voltage or pressure, from the small model dynamo,

giving a few volts, up to the huge alternating generators delivering current at a pressure of 60,000 volts or more.

If there is only a very small resistance put in the path of a current, then it requires but a small pressure to send the current through the circuit. We can easily send an electric current through a bell and quite a long circuit of wire, with the pressure of about one volt, so that a single battery cell will suffice. To send the current through a small electric glow lamp, in which the carbon filament is very short, we only require a pressure of a few volts, but for the long carbon filaments of an ordinary glow lamp we must have a pressure of one hundred volts or more. If we connect an ordinary glow lamp to a battery, we do not get any light, because the battery does not give sufficient current to make the filament white hot; we require a certain *amount* of current to light the lamp. We could, of course, make up a battery of a large number of cells which would give sufficient pressure and sufficient current, but this would not be an economical method. We have to keep in mind that no chemical cell, even though it is an accumulator, can give more than about two volts pressure. The accumulator or storage battery has a larger capacity than a primary cell, and can therefore supply a larger amount of current.

We can easily understand that a considerable pressure is required in order to force the requisite current through a very fine carbon filament or across the space between the carbon pencils of an arc lamp; but why talk about delivering current at 60,000 volts? Does any lamp or other electrical device offer so

great resistance as to require such an immense electric pressure? Certainly not; but if we erect a very long line to transmit electric power to a distance, this long line will offer considerable resistance. Every mile of wire will mean a certain additional resistance. Of course, we may use a conductor of large diameter, and thus provide a fairly easy path for the current, and if we make the conductor large enough we do not require a very high voltage. As the conductors, however, are made of copper, we should soon sink a large capital in providing very heavy wires. It is therefore economy to use as light conductors as are practicable, and as these offer a great resistance, it is necessary to increase the pressure accordingly. To distribute current economically over a tramway system we may have to use a pressure of 6000 volts, but to transmit power over a distance of one or two hundred miles we find it economical to use a pressure of over 60,000 volts.

We have only reached this high pressure by gradual stages, and there is no saying how much higher voltages our immediate descendants may use. When delivering a lecture in Johannesburg, during the visit of the British Association in 1905, Professor Ayrton drew attention to an interesting fact. He remarked that Industrial Electricity and Johannesburg were born within a few years of each other, in the eighties of last century, and that the race between the two youngsters had been for a long time neck and neck. By 1888 the male white population of Johannesburg had reached 2000, and the highest electric pressure then in use was 2000 volts. By

1897 the male white population of the busy Transvaal town had grown to over 32,000, while curiously enough in the same year two electric transmission lines were erected with a pressure of 33,000 volts. In 1898 the highest working pressure in the world was 40,000 volts, and the male white population of Johannesburg was also about 40,000. Then came the war, and volts beat white man, for, according to the census of 1904, the male white population of Johannesburg was only a little over 50,000, while several transmission lines had attained to a pressure of 60,000 volts.

Before leaving the subject of voltages, it will be well to fix in one's mind the fact that the number of volts does not signify the quantity of electricity passing along a line, but merely indicates the pressure at which the current is being delivered. If we desire to send a certain amount of power over a line, we may send a large rate of flow at a low pressure, in which case we require a large conductor, or we may send a small rate of flow at a very high pressure to do the same work, and in the latter case we can use a much smaller copper conductor.

In order to measure the working value of water flowing in a pipe we must know more than the pressure at which it is being delivered. We require to know its rate of flow, which we say is so many gallons per minute. We must have an equivalent measurement in electricity. As some new word had to be coined to express the unit of current strength or rate of flow, it was a happy suggestion to immortalise the name of the great French scientist, Professor Ampère. When we use the word ampere

to denote this electrical unit, we find it more convenient to omit the accent as used in the proper name. If one remembers that the ampere in electrical measurements is used in a similar sense to the words "one gallon per minute," there should be no confusion. We may say that it requires a current of two amperes to make a certain glow lamp light up, or that we must have a current of twenty amperes for a certain arc lamp. These statements merely imply the current strength or rate of flow of the current. They are not measures of quantity.

How are these two units, the volt and the ampere, related to each other? It will be of service to return to the analogy of water flowing through a pipe. If the water is being delivered at a low pressure we must have a considerable rate of flow, or in other words a large volume of water, to do any work, and we consequently require pipes of a large diameter to conduct the water. The electrical side of the analogy will be clear as we go along. If we increase the pressure of the water we may use less water and consequently smaller pipes. A flow of a very few gallons per minute, in a small pipe, at a high pressure, may drive a water-turbine, and do the same work as hundreds of gallons per minute passing over a waterwheel at a low pressure. It is therefore apparent that the power of doing work is dependent upon both the pressure and the rate of flow. If we increase the pressure then we may reduce the rate of flow, or the other way about. The electrical power supplied by a dynamo will therefore be dependent upon the volts (pressure) and the amperes (rate of flow). We therefore take as the unit of power that amount obtained from

a current of one ampere at the pressure of one volt. We might call the unit of power a volt-ampere, but as this would be rather clumsy we prefer to coin a new word. Here is a fitting opportunity of doing homage to the name of James Watt, the inventor of the practical steam-engine, and so the unit of electrical power has been christened a watt. This unit, being only one ampere at one volt pressure, is rather small a measure to use in connection with the power of dynamos, and so the electrician measures by kilowatts; a kilowatt simply meaning 1000 watts. We therefore speak of a 500 kilowatt dynamo, just as one talks about a 500 horse power engine. One kilowatt, or in other words 1000 watts, is approximately equal to one and one-third horse power; or put in another way, one horse power is equal to 746 watts.

Suppose we require to transmit electrical power equal to 30,000 watts (about 40 horse power) over a certain distance. We shall have to deal with the product of the pressure (volts) and the rate of flow (amperes). We may therefore arrange to send a current of 300 amperes at a pressure of 100 volts, and our result is $300 \times 100 = 30{,}000$ watts. We may reduce the amperage if we choose to increase the voltage, for we may send a current of ten amperes at a pressure of 3000 volts and our result will be the same, $10 \times 3000 = 30{,}000$ watts. It will be remembered that the first method employing a low pressure requires a conductor of much larger diameter than is necessary with the high pressure method.

The electrical resistance of any conductor is, of course, increased by adding to the length of the conductor, and also by reducing its cross section or

diameter. There seems little room for confusion here, and yet I have found beginners thinking that the large conductor should offer greater resistance than the smaller one. No doubt it is the solidity of the conductors that leads them astray. A piece of solid metal two feet square will offer a far greater mechanical resistance than a piece two inches square. The matter should be clear, however, if one keeps in mind the analogy of the water pipe. A pipe of small bore offers a greater resistance than one of larger bore. The analogy is by no means a perfect one, for in considering the resistance of a pipe to a flow of water in it we have to take into account the pressure of the water current, whereas the electrical resistance of a wire is constant no matter what voltage is used. Electrical resistance is an inherent quality of a conductor. It is true it may increase or decrease with a fall or rise of temperature, but it is not affected by the pressure of the electric current.

We must have a unit by which we can measure the electrical resistance of a conductor. The unit has been very conveniently arranged, for it is the resistance which requires a pressure of one volt to drive a current of one ampere through it. This unit has been called the ohm, after Professor Ohm (Germany), who first pointed out that the strength of an electric current not only depends upon its pressure but also upon the amount of resistance offered by the conductor in which it is flowing. This, when stated mathematically, is known as Ohm's law. The standard ohm is the resistance offered by a column of mercury 106.3 centimetres long and one square millimetre in cross section, at a temperature of 0° Centi-

grade. The layman will perhaps form a clearer idea of the value of an ohm by taking an example employing measurements with which he is more accustomed to deal. Roughly about six hundred yards of copper wire one-tenth of an inch in diameter offers an electrical resistance of one ohm. Three hundred yards of the same wire will have a resistance of half an ohm, while sixty yards will only offer a resistance of one-tenth of an ohm. We do not know what constitutes electrical resistance; its nature is quite unknown.

The general reader may not care to go further into the detail of volts, amperes, and ohms, but it is of interest to remember that the units are so arranged that it requires a pressure of one volt to send a current of one ampere through a resistance of one ohm. It will therefore require a pressure of two volts to send the same current through a resistance of two ohms. A pressure of one volt would, however, send a current of half an ampere through a resistance of two ohms, and so on.

It may be of interest to remark in passing that the potential is not the same throughout the whole length of the conductor. The pressure or potential falls from point to point. If the circuit is of uniform resistance throughout, there will be a regular fall of potential along its length. The current strength or rate of flow (amperes) will, however, be the same in all parts of the conductor, even although the circuit be made up of lengths of wire of various diameters. The electrical energy, which as already pointed out is the product of the pressure and the rate of flow, must necessarily fall with the decrease

of pressure. We therefore speak of electrical energy being consumed although we understand that it is merely transformed into some other form of energy. The electrical energy lost owing to resistance in the conductor is transformed into heat energy. If the conductor be a large one this heating effect will not be perceptible.

It will be of interest to the layman to understand the meaning of the Board of Trade unit, generally written B.T.U. It is by this unit that the supply meters measure the amount of electrical energy taken from the mains. It is well to realise that the "consumer," as he is usually called, does not consume electricity in his lamps or motors, but merely electrical energy. As much electricity passes out of his house as enters it. The water-wheel does not consume the water which drives it round, but it uses the energy of the running water. In the present chapter we shall only consider the meaning of the Board of Trade unit, leaving the means of measuring it to be dealt with in the succeeding chapter.

Suppose we have a dynamo of fifty kilowatts, or in other words 50,000 watts. We know the power of the dynamo, but the amount of energy we can get from it will depend upon the length of time we use this power. To fix a unit of energy it is apparent we must say a certain power for a certain time. The electrical unit of energy has been taken as 1000 watts for one hour; 1000 watt-hours. That is the Board of Trade unit. It will be remembered that one watt is a current of one ampere at the pressure of one volt. Suppose current to be delivered

to the consumer at a pressure of 100 volts, he may let the current flow through his electric light installation for one hour at the rate of flow of ten amperes, and for this service his supply meter will register one Board of Trade unit. He may, of course, take half of that current for two hours, or he may spread the use of the current over any time he desires. Irrespective of the actual time in which he has used it, he must pay the price of one Board of Trade unit for the energy which that unit represents. The price of the B.T.U. varies in different localities. It may range from twopence to sixpence per unit for lighting purposes. A cheaper rate is given for power and heating purposes, as these loads will chiefly come on in the daytime when the dynamos are not called upon for much lighting power.

How far will a Board of Trade unit go? A sixteen candle power lamp may be considered to require about sixty watts, so that a B.T.U. (1000 watts per hour) will keep the lamp lighted for about $16\frac{1}{2}$ hours. It is a simple calculation: $1000 \div 60 = 16\frac{2}{3}$. If the local rate for current is threepence per B.T.U., then the cost of current for each sixteen candle power lamp should work out about one-fifth of a penny per hour. In other words, the consumer may get light from five sixteen candle power lamps for one hour at a total cost of one penny.

When one is informed that the ampere is analogous to the measure "one gallon per minute," it is natural to wonder why both quantity and time are not mentioned in this electrical unit by which the rate of flow is measured. The word ampere in order to signify a rate of flow must necessarily mean a certain

quantity in a certain time. We seldom meet the unit of electrical quantity outside of the scientific laboratory, but it has been named the coulomb after a great French physicist, who lived a century ago. This practical unit of quantity was fixed by the British Association committee at one-tenth of the absolute unit of quantity, which they had scientifically determined. It may give the reader some idea of what a coulomb is, to say that if that quantity of electricity is passed through an electro-plating apparatus it will deposit rather more than one milligramme of silver. That is the meaning of a coulomb, and the ampere is a rate of flow of one coulomb per second. With this fuller statement of the meaning of an ampere, the analogy of one gallon per minute becomes more obvious.

There are other electrical units with which the scientist deals, such as the unit of electrical capacity, which has been named the farad, after our illustrious Michael Faraday who made so many important discoveries while at the Royal Institution in London.

Another scientific electrical unit is the joule, which is the amount of work done by a current of one ampere at a pressure of one volt in one second of time. This unit of electric energy was named after the great English experimenter, Joule, and the reason why the use of this unit is confined to the scientific laboratory is that we have a much larger unit, the Board of Trade unit, by which we measure electric energy on a practical scale. The B.T.U. is equal to 3,600,000 joules (1000 watts $\times$ 60 minutes $\times$ 60 seconds $=$ 3,600,000). It is the value of the larger unit which

the general reader will desire to fix in his mind, and as already stated, this Board of Trade unit represents the energy got from a current of 1000 watts per hour, the watt being a current of one ampere at a pressure of one volt.

1

2

1. A simple radiometer set in motion by the ether waves produced by the flame of an ordinary taper.
2. Electric currents passing through the fixed coils set up an ether disturbance, which causes the egg-shell to spin round on its end.

(See chap. xviii.)

CHAPTER XX

ELECTRICITY METERS, &c.

Instruments for measuring pressure, and rate of flow—A helpful analogy—Electricity supply meters—Three different principles of meters—The prepayment meter

In the preceding chapter we have considered the meaning of the different electrical units, and in the present chapter we shall deal with the methods by which we measure electricity in terms of these units.

We have a voltmeter for indicating the electric pressure in volts, and an ammeter (ampere meter) for indicating the rate of flow of the current in amperes. These are not really meters in the sense that the public understand a meter; these instruments are more akin to steam gauges, &c. They may be arranged to record the movements of their indicators if desired, but even then they only measure certain conditions of the current, the pressure and the rate of flow respectively. The principle of these measuring instruments has been referred to already. The electric current is passed through a coil of wire, thus setting up a magnetic field in its immediate neighbourhood. A magnetic needle, fixed upon a spindle, is placed within the sphere of influence of the coil, and is deflected according to the strength of the magnetic field produced by the current in the coil. But how can we distinguish between volts and amperes, between pressure and rate of flow?

What is the difference between a voltmeter and an ammeter? The only difference in construction is that in the voltmeter the current has to pass through a coil of very fine wire, while in the ammeter the coil is made of a heavy or coarser wire. It is difficult to find any very suitable analogy for this point, but suppose we desire to measure the rate of flow and the pressure of the wind. To measure the former, we erect a very light windmill on the top of a pole, and we adjust the mechanism so that when a certain amount of wind has passed, the windmill will have been driven round a definite number of revolutions. We might arrange that half a mile of wind would turn the windmill fifty thousand times, so that we would use means of registering the number of revolutions, and by this we could reckon the rate of flow of the wind. To measure the pressure of the wind we shall be content with a rather rough-and-ready apparatus for the sake of our analogy. We erect a pressure plate held forward by a strong spring of known tension. We can then note the pressure of the wind against the power of the spring. Such an arrangement would not be very accurate, and even properly arranged pressure plates are seldom used in observatories, as we have mathematical tables by which the pressure may be calculated from the rate of flow. However, the point of assistance to us, by way of analogy, is that when we measure the rate of flow of the wind we place as little obstruction as possible in its path, the small windmill being made of aluminium and delicately poised. In the ammeter by which we measure the rate of flow of an electric current we place as little resistance as

possible in the path of the current, hence the large conducting wire in the coil, which offers practically no resistance. To measure the pressure of the wind, we place a very considerable resistance in its path, and then note the effect produced. To measure the pressure (volts) of an electric current we place a considerable resistance in its path, making it go through a coil of very fine wire.

Leaving the wind analogy out of account, we may now get a clearer view of the matter in this way. In the ammeter we require practically no pressure to send the current through the heavy wire, hence the variations in the magnetic field will be due to the rate of flow of the current, which is the same at all parts of the circuit. In the voltmeter we have, on the other hand, so blocked the way of the current that it is a reading of its pressure we get. More accurate voltmeters and ammeters are made, just in the same manner as the siphon recorder is a more delicate form of the needle telegraph or needle galvanometer. It will be remembered that in the siphon recorder there is a stationary magnet and a moving coil. These "moving coil" voltmeters and ammeters do not have the whole of the current to be measured passed through them, but only deal with a definite proportion of the whole current. There are also electro-static voltmeters and ammeters, but the instruments just described will serve to show how we measure the pressure and the rate of flow of an electric current.

As it is according to the Board of Trade units registered that the consumer has to settle with the Electric Light Company, he is perhaps more in-

terested to know the principle upon which his supply meter works. Although this electricity meter is analogous to a gas or water meter, the electricity meter seems much more mysterious than the gas and water meters through which known material substances are passing. We have already seen that we can only measure electricity by its effects, and in this case it is the energy of the electric current, drawn from the mains, which we desire to measure. One method very widely in use is to cause the incoming current to set up a magnetic field and drive an armature round. In some cases the armature is a simple copper disc, and this revolving disc drives a train of wheels which indicate on small dials the amount of energy taken from the mains. Electricity meters of this class are practically small electro-motors, and they do not really register the electrical energy, but merely the quantity of electricity supplied, and it is taken for granted that the supply company will keep the pressure of the current up to the stated voltage at which they undertake to deliver it. If the pressure in the mains falls below the specified voltage, then the consumer is not getting the full energy from the current. Care is taken, however, at the generating station to keep the voltage up to the specified pressure. Some meters, usually termed wattmeters, are designed to take into account both the variations of current strength and of voltage, but as supply companies keep their mains at some constant pressure, the "ampere-hour meter" as just described is quite satisfactory.

The energy of a current may also be measured by its chemical effect, and we have several supply

meters constructed on this principle. In one form of electrolytic meter the current decomposes a column of water into its constituent gases, hydrogen and oxygen. These gases escape from the tube, leaving the level of the water lower, and the amount of energy of the incoming current is indicated by the quantity of water which has been decomposed. A scale is marked off in similar manner to that of an ordinary thermometer, but the degrees in the former case represent Board of Trade units.

Still another method of measuring the electrical energy consumed is to use the magnetic field, produced by the incoming current, to act as a drag upon the pendulum of a clock-work mechanism, the clock-work being self-working. Sufficient detail, however, has been given to show the general principles upon which electricity meters work. The best meter is, of course, the one that consumes the smallest amount of electrical energy to operate its mechanism.

A prepayment or "penny-in-the-slot" meter is an ordinary supply meter with a mechanical arrangement by which a coin, dropped into it, switches on the current, and when the meter has registered the equivalent value in electrical energy the current is automatically cut off.

CHAPTER XXI

MEDICAL APPLICATIONS

Electric frauds—Decisive victory over lupus—Different methods of treatment—The Finsen lamp—Roentgen rays—High potential currents—Remarkable currents passed through the body without sensation—Other electrical applications—Ionised air—The value of being able "to see through and through" a patient—Some hospital cases—A false alarm—The dentist and X-rays—Ozone as a disinfectant—Electric cautery—Removing steel from an injured eye

ELECTRICITY is such a mysterious agent that we should have been surprised had not the "quacks" sought to work wonders by imaginary electrical powers. I well remember when electric hair-brushes were considered a marvel. As proof of their electrical power, the intending purchaser was shown their effect upon a compass needle, and many people were thus convinced that the brush was a powerful electrical instrument. Finding many well-educated people persuaded of the genuineness of this new therapeutic agent, I opened up the wooden part of one of these brushes, and found, as I had expected to find, an ordinary toy steel magnet enclosed within the wood. This served to deflect the compass needle, but the brush was no more an electrical agent than any ordinary hair-brush is. Many of us recollect the electric belt frauds which came up in some of our law courts in the earlier days of electrical enterprise. The public

understands more of electricity to-day than it did then, so that the chance of success for such frauds is fortunately not very great.

During recent years the medical profession has taken the subject of electricity seriously in hand. All the important hospitals of to-day have their electrical departments. Much of this subject is still in an experimental stage, but in some branches rapid strides have been made, and wonderful success has been attained. The most outstanding of these is the "light" treatment of that distressing cutaneous disease known as lupus. We are doubtless all acquainted with the disfiguring appearance of this disease, and we are aware of the great difficulty that surgeons have experienced in dealing with it. Very remarkable cures are now accomplished by exposing the affected parts to the rays emitted by certain electric lamps, of which the Finsen (Denmark) was the pioneer. It had long been known that the arc lamp, and other sources of light, gave out not only visible luminous rays but invisible heat rays, and actinic or chemical rays. It is these chemical rays which have proved so beneficial in cases of lupus. Finsen focussed the rays of a powerful arc lamp (10,000 candle power) by means of a telescope tube having two quartz lenses in it. There are now many modifications of this lamp. The apparatus is kept cool by water circulating through it, and the affected part of the patient under treatment has a small water-cell firmly pressed against it. This compressor serves a double purpose : water is kept circulating through it, so that it ensures the absorption of any heat rays passing out of the water-cooled lamp ; and the second

purpose of this water-cell is to press out the blood from the tissues of the affected part, thus rendering it as anæmic as possible. This latter use is of much importance, for if much blood remained in the affected part, the beneficial rays would be stopped by the blood corpuscles, and would therefore not be able to penetrate the diseased tissue. These chemical rays of ultra-violet light are very easily obstructed.

One has only to pay a visit to any of our large hospitals to see what an important position this "light" cure has now taken in therapeutic work. To see the photographs of patients before and after treatment must convince the most incredulous that electricity has indeed scored a great victory. It has been found that Roentgen rays also possess a similar power of stamping out this persistent disease, and some medical men prefer to vary the treatment, sometimes using the one method and sometimes the other, for the same patient; but in hospital work it is now usual to decide upon one treatment or the other for each special case. In a large hospital we may find as many as twenty lupus patients simultaneously under treatment by light, while three or four are being treated by Roentgen rays. It is not necessary that these patients should remain in the hospital, for the rays are only applied for a short time, and the reaction allowed to subside. The treatment may extend over a period of many months. During the operation the patient may lie on a couch reading, while a nurse presses the water-cell on the affected part.

In cases where it is impossible to employ those rays, on account of the position of the affected part,

high potential currents have been used, and these have proved of considerable service. High potential discharges are produced by large induction coils and specially constructed induction apparatus, or in some cases large Wimshurst machines are brought into play. When a stranger sees the immense brush discharge from such apparatus he may be somewhat alarmed, till the surgeon demonstrates that these high potential currents may pass through the body with perfect safety. They produce no disagreeable sensation whatever. A vacuum tube may be held in the mouth and made luminous by a current passed through the sensitive membranes of the mouth. Half-a-dozen glow lamps may be lighted up with current passed through the body, and yet no sensation is felt. A similar alternating current at a greatly reduced rate of oscillation would do serious hurt, and might indeed prove fatal. High potential currents are more in evidence in American hospitals than in this country.

In the electrical department of the hospital we find under treatment cases of nervous affection, paralysis, rheumatism, writer's cramp, &c. Sometimes we find the masseur's place taken by a massage ball operated by an electric motor. It has even been proposed that high-frequency current might be used as an anæsthetic for superficial operations. Experiments made upon animals have shown that a condition may be produced, during which the prick of a needle or the burn of a hot iron have not been felt. Electric baths are in use, but these are simply means of passing electric currents through the body, and therefore call for no special remark, further than

pointing out that it is not necessary for the patient to be bodily in the bath. The patient may have each leg and arm in a separate bath, and with a conveniently arranged switch-board the current may be passed from arm to arm, or leg to leg, or from the right arm to the left leg, and so on.

Ionised air, which is produced by forcing air through a chamber in which there is a powerful electric arc maintained, has been tried as a therapeutic agent, but this so far is experimental.

Sufficient detail has been given to enable the reader to form a proper understanding of electro-therapeutic methods; to enter into details of medical cases would be out of place in a work of this character.

Passing to the department in which X-ray observations are made, we find a great deal of interest attached to it. This is a busy department in a large hospital. First of all a mother brings her child along and tells those in charge that the little one has swallowed a farthing. The child's clothes are removed from the upper part of the body, so that buttons may not be mistaken for coins. The little one stands on a table in front of an X-ray tube. The rays pass through the body and illumine the fluorescent screen, which the operator holds in front of the child. In a moment the child's whole anatomy appears upon the screen, and the lost farthing is seen sticking in the œsophagus or gullet. The electrician writes out a brief description of the position in which the coin is lying, and handing it to the mother, directs her to one of the house surgeons, who deftly fishes it up with the aid of a "coin catcher."

The next case is a man suffering from an unaccountable pain in one of his feet. The X-rays discover a darning-needle embedded between the toes, quite unknown to the patient. Sometimes, of course, there are false alarms. For instance, a man was brought to one of our great London hospitals suffering considerable pain from having swallowed his artificial teeth while asleep. The X-ray operators were preparing to examine him, when one of the hospital porters appeared upon the scene with the information that a little girl had come to say that her father's teeth had been found beneath the bed. The swallowing feats are usually performed by children, and it is remarkable what they can swallow. One of our hospitals had the case of a child who actually swallowed a toy bicycle. It had, of course, stuck in the œsophagus, or, as one sometimes merely says, "in the throat," forgetting that the throat contains both the gullet and the windpipe. The X-rays showed that the handle-bar had caught, so that it was necessary to make an incision in the œsophagus, but almost no scar remains. The toy was cut in two and safely removed. When the little girl of four and a half years was told by one of the doctors to keep a long string on any more bicycles, she replied that she had no more bicycles but she had a motor-car (see *Frontispiece*).

I remember seeing an interesting X-ray photograph of the arm of an elderly lady. She had fallen and injured her arm, and the surgeon "X-rayed" it to find if any injury had been done to the bones. The photograph showed that no bones had been broken, but it discovered incidentally a broken

needle embedded in the tissue of the wrist. The patient had no knowledge of this, and it is possible that she had carried it about in her body for the greater part of a long lifetime.

The X-rays are now used for examining numerous internal disorders. They have proved of great service to the dentist in enabling him to see in what position the roots of troublesome teeth are embedded in the jaw. If a wisdom tooth, in a young person possibly twenty years of age, refuses to make its appearance and begins to give trouble, the dentist may have an X-ray photograph taken of the patient's jaw, and thereby see the cause of the trouble. It is impossible to overrate the value of the searching Roentgen rays to the medical profession.

In chapter xi. I had occasion to refer to the production of ozone, or concentrated oxygen, in connection with the subject of lightning (page 161). Ozone exists in the atmosphere in minute quantities. It is more easily detected in country districts, for in towns it is too easily absorbed by the smoke and dirt in the air. The therapeutic value of ozone lies in its remarkable power of oxidation. Bacteria are rapidly destroyed by exposure to it, so that the air of a room or public building may be purified and disinfected by a liberal supply of this allotropic oxygen. In the proceedings of the Imperial German Sanitary Board there is published the following statement in a report upon the effect of ozone on bacteria: "Anthrax, typhus and cholera bacilli, contained in sewage water of the river Spree, were destroyed." Ozone has, therefore, a valuable sanitary property, and makes a pleasant disinfectant. Air

may be ozonised by subjecting it to high-tension electrical discharges, and specially constructed ozonising apparatus is now made on a commercial scale.

In addition to the therapeutic effects of lupus lamps, X-rays, high-frequency currents, &c., the medical man calls electricity into play in other directions. Small electric lamps, not much larger than a full-sized pea, may be used to illumine dark cavities of the body. We find still another service in connection with cautery. When it is necessary to remove any obstructing tissue, such as often occurs in the upper part of the nose, the surgeon may do so electrically without much inconvenience to the patient. A small instrument, having a short platinum wire at its point, may be inserted up the nostril, and then the current switched on by closing a small contact spring on the handle of the instrument. The instrument is quite cool until the current is turned on, and this is not done till the instrument is in contact with the obstructing growth. The red-hot platinum then burns away the obstruction, which has been previously anæsthetised by means of cocaine.

It has often been found a very difficult matter to remove very small pieces of iron or steel from an injured eye, but the task is now simplified by the use of a large electro-magnet, as shown in the accompanying illustration (page 302). The end of the magnet is shaped as a cone, and is supplied with a small brass tip, which screws off and is treated antiseptically. There is also a small brass ring against which the patient may rest his face. The distance is so arranged that the patient's eyelashes just touch the brass tip of the magnet.

This large magnet has also proved of much service in removing pieces of iron from other parts of the body. If the wound is recent, the metal will fly out when the electric current is switched on to the magnet. If the wound has been healed for years, the magnet may be used in the first place for diagnosing the exact position of the metal. When a weak current is sent through the coils of the magnet, the patient feels where the metal is. The current may then be increased till a protuberance rises, and if a simple incision is then made, the metal will be drawn out by the magnet. In one case, a piece of metal was removed which had been embedded in the patient's hand for more than seven years.

The second illustration shows the very powerful magnetic field surrounding the magnet. A man is sitting with the back of his head to the pole of the magnet, and a number of separate pieces of iron and steel are held together over his face by the magnetic attraction.

1

2

By permission of *The Scientific American*

1. Removing a piece of steel from an injured eye by means of a large electro-magnet.
2. Pieces of iron and steel held in position by magnetic attraction.

(See chap. xxi.)

CHAPTER XXII

POSITIVE AND NEGATIVE ELECTRICITY, &c.

Are there two kinds of electricity ?—How electrified bodies behave towards each other—The positive and negative terminals of a battery or dynamo—The meaning of self-induction—An analogy—The action of the induction coil—The advantage gained — A common stumbling-block to the layman — The different kinds of currents—Three-phase dynamos—How the X-rays are produced—Photographing the skeleton—Seeing the anatomy of a patient on a screen—An X-ray fraud—A convenient arrangement for observing by X-rays

So far I have purposely avoided the use of the terms positive and negative electricity. Are there two kinds of electricity ? We really do not know. We do not believe in the existence of two ethers, but there may be two different manifestations of the same ether. There are certainly two kinds of electrification, and this may be demonstrated by one of the simplest and earliest of electrical experiments.

We know that an electrified body attracts any light object. In order to examine the conditions of this attraction we suspend, by means of a thread of silk, a very light ball about the size of a pea and made from the pith of an elm tree. We use this pith ball simply because of its small weight ; it will be so easily moved. We suspend the silk thread from a glass pillar or other insulator, so that whatever electrical

charge we give to the pith ball cannot escape from it. After "exciting" a vulcanite rod, by means of a fur rubber, we bring the rod towards the pith ball, which immediately jumps forward to meet the rod. We withdraw the rod, to which the ball clings, but in freeing the ball from the rod we are careful not to touch the ball, as we wish it to retain the charge of electricity the rod has given to it. We again bring the electrified vulcanite rod towards the pith ball, which is now electrified also, whereupon we find that it is forcibly repelled from the rod. Do electrified bodies repel one another then? Not necessarily so, for if we excite a glass rod by means of a silk rubber and bring this electrified rod towards the electrified pith ball, we find that the ball is attracted to it, although the ball still flees from the electrified vulcanite rod. To make this matter as clear as possible, it will be an advantage to suspend two pith balls from separate supports. We first of all electrify one ball by contact with the electrified vulcanite rod, and we find that this electrified pith ball attracts the other non-electrified one. We discharge the electrified ball by simply touching it with the hand, and thus allowing its charge to escape to earth. There is, of course, no sensation produced by so small a charge. We then electrify the same pith ball by contact with the electrified glass rod, and we find that this ball attracts the other non-electrified ball just as it did before. Therefore any electrified body will attract a non-electrified body. When we electrify one ball by the vulcanite rod and the other ball by the glass rod, we still find the same attraction between the balls. It is only when we electrify both balls by the vulcanite rod, or both by

the glass rod, that we find repulsion.[1] Here we have the same law at work as we find in connection with magnetism. A magnet attracts a piece of non-magnetised iron equally well by either pole, and the north pole of one magnet will attract the south pole of another magnet, but the two norths, or the two souths, will repel each other.

Franklin suggested that the two different states of electrification were due to a surplus in the one case, and a defect in the other, of a mysterious fluid, and it was in connection with this idea that the terms positive and negative came into use. We still use these terms, but they are merely arbitrary signs, and are conveniently written down as + and −. By the word "arbitrary" I mean that there is no reason why the one condition should be positive more than the other. Further remarks regarding positive and negative electricity will fall more naturally under the title of the succeeding chapter.

In passing we may here note that in practice we speak of electricity always flowing from the positive to the negative point. From Lord Armstrong's experiment, described on page 265, we saw that there was evidence of two distinct electrical currents flowing in opposite directions. When we say that a current of electricity is flowing along a wire, we therefore speak only of the positive current. In a battery or dynamo the positive terminal is the point at which the current enters the circuit or mains, and the negative

[1] Electricity produced by a glass rod used to be called vitreous electricity. That obtained from sealing-wax, or in the present case vulcanite, was termed resinous electricity; some scientists still prefer these terms. The same result may be obtained by exciting many other substances. In fact, all substances belong to one class or the other.

terminal the point at which the current re-enters the battery or dynamo.

A gentleman, who was about to make some experiments in electro-plating, telephoned to me to say that the text-books which he had beside him seemed to be at sixes and sevens as to which was the positive and which was the negative plate of a battery, so much so that he was at a loss to know to which electrode in the electro-plating bath he should attach the article to be plated. There is really no confusion in the matter if one remembers that the current is flowing through the battery as well as through the outer circuit. The current, of course, originates in the battery, and as zinc is electro-positive to carbon, or at a higher electric level, we speak of the current flowing from the zinc plate inside the cell through the liquid to the carbon plate. We therefore call the plate of zinc the positive plate and the carbon the negative plate. But the current having flowed through the liquid from zinc to carbon, it is bound to flow from the outside terminal of the carbon to the outside terminal of the zinc. Hence the terminal attached to the carbon plate is the positive terminal, although the carbon is the negative plate ; and the terminal of the zinc is the negative one, although the zinc is the positive plate. Keeping the complete circuit in view, there should be no occasion for confusion.

In some of the earlier chapters we have seen that when an electric current is flowing through a circuit and it is suddenly broken, there is a spark produced between the ends of the wire as they separate. We may bring the same ends ever so close together, but there is no spark ; it is only at the moment of break-

ing the circuit that the spark occurs. In considering the arc lamps we observed that it was necessary that the carbon pencils should first of all touch each other before the current could leap the small air space between them, but that once started it was maintained across a bridge of carbon vapour. We are told that this spark which occurs upon the sudden breaking of a circuit is due to "self-induction," but to the layman this is rather mystifying. He may understand it better by considering the effect to be due to inertia.[1] The electric current is travelling through the wire when it is suddenly stopped, but it lurches forward, and the momentarily increased pressure causes the current to leap the small air space. Some physicists may consider this inertia as an analogy, others believe it to be a statement of fact; that electrical inertia, or self-induction, is identical with ordinary inertia.

We have a very forcible example of inertia in connection with any vehicle travelling at a high rate of speed. A motor car is suddenly brought to a standstill in order to prevent an accident, but the occupants are shot out of the car with considerable force. We experience the same lurch forward when a train or electric tramcar is suddenly pulled up. This inertia is what we call self-induction in electrical matters.

[1] The word inertia implies laziness of matter to move or to stop moving. The layman will possibly have more difficulty in realising the latter condition. He can well understand that matter requires energy to be applied to it in order to move it, but he is so accustomed to see all moving objects on this earth come to rest that he cannot so easily realise that matter would continue to move unless some outside force, such as friction, was applied to it. He has only to look at our faithful satellite the moon to see an example of a body continuing incessantly in motion.

The electric current is inert or sluggish in making any change. It is lazy to start or to stop.

This discussion leads us to the consideration of induction coils. I have had occasion to mention induction coils repeatedly in earlier chapters, but the present seems the most suitable opportunity of explaining the action of these. We take a coil of coarse wire through which the electric current from a battery may pass with little resistance, but we arrange to make and break the circuit very rapidly. At each break there will be a sudden lurch forward of the current in the coil, and this will so disturb the surrounding ether that if we place a second coil of wire in the neighbourhood of the first coil this ether disturbance will set up a momentary current in the second or secondary coil. This secondary current only occurs at the moment the circuit is made and broken in the first or primary coil. We may think of there occurring, in the primary coil, a sudden lurch forward of the electric current, or an electric push, and by making and breaking the circuit of the coil rapidly we produce a pulsating current, which through the medium of the intervening ether sets up a corresponding series of electric pushes in the secondary coil. The induced current always tends to oppose the change that is taking place. The advantage to be gained is that we may cause the ether disturbance, set up by the primary coil, to operate upon a secondary coil having a greater number of turns; we might have sixty coils or turns of coarse wire carrying the current in the primary, and ten thousand coils or turns of very fine wire in the secondary coil which is placed in the ether disturb-

ance. The result would be that while we have a large rate of flow of current at a low pressure, in the primary coil, setting up the ether disturbance, there is a small rate of flow of current at a very high pressure in the secondary. We have not, of course, increased the available energy. We have merely increased the pressure (volts) at the expense of the rate of flow (amperes). We have, therefore, a convenient method of producing high potential currents, as referred to in the preceding chapter.

In an induction coil the secondary circuit is wound upon the top of the primary circuit, great care being taken to thoroughly insulate the one coil from the other. In the large Spottiswoode coil mentioned on page 267, there are only about one thousand turns of wire in the primary circuit, and over three hundred thousand turns in the secondary circuit. The length of wire going to form the primary is less than half a mile, while the secondary has a length of two hundred and eighty miles of wire.

The inertia in the primary circuit of all induction coils is greatly increased by placing a soft iron core within the coil. A "condenser" formed of sheets of tinfoil, and equivalent in action to a Leyden jar, is attached as a reservoir for the primary coil. This condenser is not, of course, a part of the direct circuit through which the battery current has to pass, but is a shunt circuit, as it were, and merely increases the electro-static capacity of the circuit. The means of making and breaking the primary circuit may be automatic. The iron core of the primary coil may alternately attract and let go a metal spring, exactly as was described in connection

with the trembler bell (page 166), and the to-and-fro movement imparted to this spring piece serves to switch off and on the current very rapidly, or, in other words, we get a quick make and break. In large induction coils such as used for high-frequency currents, or for X-ray work on a large scale, it is usual to provide a mechanical make and break arrangement, driven by a small electro-motor. There are also electrolytic interrupters for the same purpose; but sufficient detail has already been given.

In describing the action of the induction coil I have only dealt with the inertia due to the stopping of the current. There must also be a lurch backwards at the moment of starting the current, and this too must set up an ether disturbance and induce a momentary current in the secondary circuit. This lurch backwards at the starting of the current is not nearly so effective as the lurch forward at the stop. We may consider the lurch at the start as being spread over a greater time; a slower movement. The difference between the two impulses is so great that the total effect produced in the secondary is just as though the impulse due to the starting was absent. It may be clearer to some to picture the starting impulse, in the primary, as not giving sufficient pressure to force a current through the great resistance of the secondary coil, so that the effect is practically lost. The purpose in mentioning this matter in such detail and in this pictorial manner is with the hope of clearing up a point which I have very often found to be a stumbling-block to the layman. One is instructed to connect a certain terminal of an X-ray tube to the positive ter-

minal of his induction coil, but he asks where the positive terminal is. He reasons that if there is a current set up alternately in opposite directions, each terminal must be positive and negative alternately. It is, therefore, well to understand clearly that we have only to take into account the one current which is set up at the break of the primary circuit.

In the foregoing account of the action of the induction coil, I have had occasion to use the words "pulsating current" as descriptive of the kind of current flowing in the primary or battery circuit. Pulsating currents are not alternating in direction, but flow always in one direction only. The only difference between a current of this class and a direct or continuous current is that the pulsating current is not a steady flow of current, but pulsates at regular intervals, producing as it were waves of current. An alternate current, on the other hand, is rapidly and periodically changing its direction of flow. The alternate current from a dynamo may reverse its direction from fifty to three hundred times each second.

I have also had occasion to speak of a three-phase current in connection with the rotating egg experiment, described on page 267. In an alternator, which is a dynamo used for producing alternating currents, we must have the current rising and falling in value as it changes from one direction to the other. There will be a maximum positive and a maximum negative alternately. One such complete oscillation is called a phase. The current in some parts of the revolving armature coils will be at a maximum, while others will be at a minimum, depending upon the relative

positions in the magnetic field which they happen to be occupying at the moment; one section or coil enters the magnetic field in advance of another section. We can, therefore, tap the revolving coil at three different places if desired, and lead out the currents at different phases. Perhaps it will be simpler to think of three separate coils revolving one after the other. These three currents have their maxima occurring at different moments, so that the resulting current has not the sudden rise and fall present in a single-phase current. It is in connection with electric traction that two-phase, three-phase, or polyphase currents are of importance. To understand these currents clearly one must put the different "curves" down on paper; I have purposely avoided the use of diagrams throughout this book, with the exception of the two relating to dynamos.

It will be of interest to the layman to understand how the X-rays are produced. It had long been known that if a high potential current, such as is obtained from an induction coil, was passed through a so-called vacuum tube,[1] a tube from which as much air as possible had been extracted by means of an air-pump, the remaining contents of the tube became beautifully luminous. The effect produced has the appearance of a stream of luminosity from the one electrode to the other. The electrodes merely enter the tube at its opposite ends, so that the so-called vacuum is the connecting link from one electrode to the other. The stream of luminous rays was

[1] If the tube was in reality a vacuum no current could pass. It is the small quantity of air which acts as the conductor.

named the cathode rays, as these emanate from the cathode or negative electrode. The cathode stream is sometimes spoken of as radiant matter. If a piece of platinum is placed in the path of these flying particles, the bombardment is so great as to raise the metal to a red heat. This stream of radiant matter may be deflected from its straight path by presenting the pole of an ordinary steel magnet to the side of the tube.

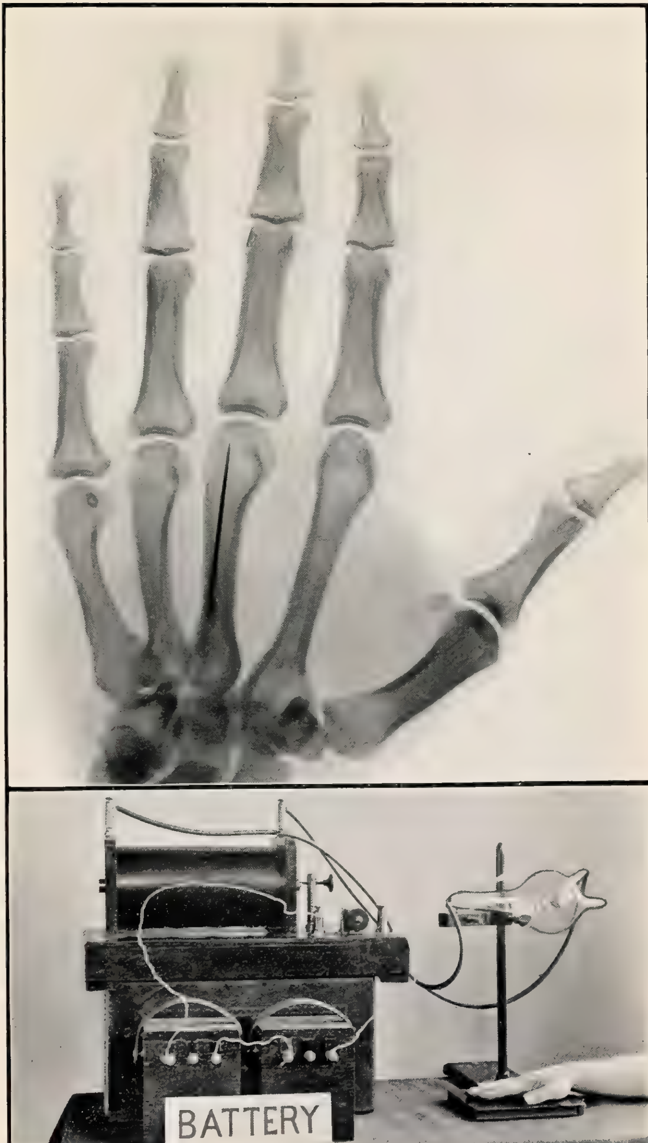
Professor Roentgen, of Wurzburg (Germany), discovered that if these cathode rays were suddenly stopped by striking against the walls of the glass tube, or, better still, against a platinum disc placed in their path, there was an energetic disturbance produced in the ether. The waves or rays thus set up in the ether were called by Roentgen X-rays, signifying unknown rays, but others have christened them Roentgen rays in honour of the discoverer. These Roentgen rays are quite invisible, but they affect the chemicals on a photographic plate, just as the rays of ordinary light do. There is a great difference, however, in the penetrating power of X-rays and ordinary light. The X-rays will easily pass through substances which are quite opaque to light.

In the accompanying illustration we see the method of taking an X-ray photograph of the hand. There is no camera; the photographic plate is merely placed under the hand, the sensitive plate being, of course, protected from ordinary light by enclosing the plate in a dark envelope. The X-ray tube is connected to the induction coil, and the cathode rays bombard the aluminium disc upon which they are focussed, and

from this point the X-rays are set up in the ether. These invisible rays pass out of the tube and penetrate the hand, and passing through the dark envelope they reach the photographic plate. The flesh of the hand offers a little resistance to the passage of the rays, so that a faint shadow of the flesh of the hand is seen. The bones offer much more resistance, being at their thickest parts nearly opaque to the rays, so that their outline is clearly depicted upon the developed negative. As metal is still more opaque to the rays, it is easy to locate any metal object embedded in the hand. It will be apparent from the accompanying photograph that a needle may be seen even through the bones of the hand, for the rays have encountered the bones and then the needle.

It is sometimes unnecessary to produce a photograph, and in many cases it is more convenient to be able to see the skeleton, &c., without waiting to develop a photographic plate. How can we see by means of invisible rays? All light rays are really invisible; they only produce a sensation of vision when they impinge upon the retina of the eye. These X-rays do not stimulate the retina at all. If these rays, however, fall on a screen upon which certain fine chemical crystals have been fixed, their condition is so altered that they produce vibrations to which the eye is able to respond. We may picture the X-rays, according to present ideas, as being a sudden pulse or splash in the ether, caused by the sudden stoppage of the cathode rays. The X-rays are therefore not looked upon as a train of waves.

The X-ray screens are usually made of fine crystals of barium platino-cyanide spread over a parchment



TAKING AN X-RAY PHOTOGRAPH

The lower illustration shows exactly how the photograph is taken; there is no camera used.

The upper illustration, showing the appearance of a needle in the hand, is by Mr. John Trotter, Glasgow.

screen, and these are known as fluorescent screens. When held in the path of the X-rays the whole screen becomes beautifully luminous. When the hand is held at the back of the screen, so that the hand comes between the screen and the X-ray tube, the skeleton, &c., of the hand is seen upon the front of the screen with remarkable clearness. It is necessary to have a luminous screen upon which the skeleton may be seen in shadow. I remark this because I recently saw a fraud perpetrated in this connection. Passing through one of our great cities along with a friend, we noticed a large placard bearing the words, "Living Skeleton seen under the Roentgen rays." The show had a decidedly tumble-down-looking appearance, so I was curious to see what kind of X-ray apparatus the showman possessed. The audience were first of all shown a girl, in ordinary dress, standing at the end of a passage. I presume it was only a reflected image of the girl that was seen, for she began to fade away, and a skeleton gradually appeared in her place. The skeleton was light upon a dark background, and was certainly produced by ordinary reflected light. Judging from the remarks I overheard, it was evident that the audience went away with the false idea that they had seen a genuine X-ray demonstration. In such circumstances one does not care to interfere personally, but I took care that, when we were passing out, the showman overheard me remark to my friend that there were certainly no Roentgen rays in that show.

It may be pointed out in passing that, when a patient is being examined by means of the X-rays, there is no necessity for the patient to be in the dark. It is much more convenient to have the apparatus

and the electrician in the light, and it is only necessary that the observer and his luminous screen should be in the dark. The observer may take the fluorescent screen into a portable "dark room," consisting of a dark cloth enclosure with a roof on it. The medical man may keep this dark room, when not in use, folded up like a draught screen. The electrician being in the light, can make any necessary adjustments of the apparatus more easily. If the patient be a child, it is an advantage that the room does not require to be darkened.

CHAPTER XXIII

PRESENT IDEAS OF ELECTRICITY

The ether—The unit of negative electricity—The corpuscle—What makes the atom—How atoms unite to form molecules—Cohesion—Gravitation—A drop of water mentally reduced to ether—A dark and silent world—Newton's idea of the ether—What is an electric current?—A new analogy—The earth circuit—How electric pressure decreases along a circuit, but the rate of flow is constant throughout—Conductivity—Electrolysis—How a battery cell acts—What is magnetism?—The size of a corpuscle—Visible effects of the ether

ALL our present scientific conceptions are based upon our belief in the existence of a mysterious something which pervades all space, and to which has been given the name "ether." We have really no idea whatever as to the nature of the ether, but we are none the less convinced of its existence.

We read in Holy Writ that "In the beginning . . . the earth was *without form and void*," and this is perhaps as good a conception as we can form to-day of the ether. But do we mean to suggest that the world was created out of the ether? We do believe it was. Some one may ask what all this has to do with the subject of electricity. It has a great deal to do with it, and indeed it may be that some day we shall prefer to call the ether by the name of electricity. In any case electricity is nothing but the ether in motion. We might say, with some truth,

that we know what electricity is, but our difficulty is that we do not know what the ether is.

But how can the ether, which is not material, according to our ideas of matter, go to form material things? It is "without form and void"; how can it then assume material shape? We first of all picture infinitesimally small portions of ether being set into rapid vortex motion, and by way of analogy we may refer to the physical experiment of smoke-rings, which are in reality air-rings, as described on page 151. Of course, what we are trying to picture is far away below the range of visible things. This vortex ring of ether we reckon to be a unit of electricity, or we prefer to call it a unit of negative electricity for reasons which will become apparent as we go along. This infinitesimal unit of negative electricity is then nothing but some of the mysterious ether in motion. It is quite a natural step to imagine this moving electrical unit as dragging with it some of the surrounding ether; the greater the velocity the more of the surrounding ether is "bound" to the electrical unit. We believe matter to be nothing else but a great congregation of these electrical units carrying varying quantities of bound ether.

The electrical unit along with its bound ether is called an electron or a corpuscle. But can these corpuscles be detected in nature? We cannot hope to handle them or see them, they are infinitely small; but we may note their presence by the effects which they produce. Witness the work they do when they are made to bombard a piece of metal placed in a vacuum tube (page 313). The velocity

with which they strike the metal soon enables them to raise it to a red heat. These corpuscles are not particles of ordinary matter; they can exist free from matter. We believe that a crowd of these corpuscles, bound together by an envelope of positive electricity, constitutes an atom of ordinary, or gross, matter. We picture this coating of positive electricity as balancing the negative electricity of the enclosed corpuscles. Again we are encountered by an unanswerable question as to the nature of this positive electricity. We have formed a mental picture of what a unit of negative electricity is, but we can only say of positive electricity that it is a manifestation of the ether, and that it is never found apart from matter.

So far we have reached the theoretical construction of an atom of matter. We have pictured the coating of positive electricity upon this atom as balancing the negative charge of the crowd of corpuscles contained within it, but the atom may contain a few more or a few less than is required to exactly balance the positive envelope. If there are a few more corpuscles (negative), the atom will be as a whole negatively electrified. An atom with a few corpuscles less than the balance will be as a whole positively electrified; in other words the positive coating will preponderate. The chemist, therefore, speaks of some atoms being electro-positive and others electro-negative. He arranges the atoms of all the elementary substances in a table, commencing with the most highly electro-positive atom down to the most highly electro-negative atom. If these two types of atoms are free to move, they

will be attracted towards one another, just as the oppositely electrified pith-balls are. Each of these atoms, not having an exact balance between its corpuscles and its coating, is in a somewhat unstable condition. Let us suppose that we have before us an electro-positive atom with only one corpuscle short of an exact balance with its outer coating, and we also have an electro-negative atom with just one corpuscle in excess. These two atoms when attracted together, as described, would then unite together and electrically neutralise each other. This is what we now believe chemical union to be; nothing but electrical union. Suppose we had one electro-positive atom having again only one corpuscle short, and another electro-negative atom which has two corpuscles in excess, we could not get these to unite together. We should require to find a third atom exactly the same as the electro-positive one we already have, namely, with one corpuscle short. We can now get the two electro-positive atoms, which together are two corpuscles short, to unite with the one electro-negative atom, which has two corpuscles in excess. This is exactly what happens when we combine hydrogen and oxygen together, and thereby form water. Two atoms of hydrogen (H) and one atom of oxygen (O) when united give one molecule of water (H_2O).

We cannot see a molecule of water; we should require to have a drop of water magnified to the size of the earth before we could see the individual molecules of which it is built up. We know, however, that a drop of water must be composed of myriads of molecules, and that these particles of

matter cohere together. There is very little cohesion between the molecules of a liquid, as compared with those of solids. The molecules in a piece of granite rock hold on so firmly to each other that the weight of one ton is required to pull apart those occupying a section of one square inch. If the temperature of water is sufficiently reduced its molecules are then able to take a better grip of each other, and we have the resulting solidity of ice. We do not know the nature of this force which we have named cohesion, but it must surely be electrical; an effect or manifestation of the ether. We see a magnet attract a piece of iron. There is an invisible pull of a mysterious something—the ether. Is it not as easy to imagine one molecule of matter acting upon another in some similar manner?

Gravitation remains so far unexplained, but there seems little doubt that it too must be an invisible pull in the ether. We see a horse taking a heavy load down a hill. It is most apparent that the heavily laden cart is being forcibly drawn forward, and if the mass of the load be very great the horse may be quite unable to withstand the pull. We cannot get away from the idea of the ether if we seek to understand any physical problems.

We therefore believe a drop of water to be composed of a great multitude of molecules of water held together by an attractive force which we have named cohesion (Lat. *cohæreo*, I stick). Each of these molecules of water is composed of two atoms of hydrogen gas and one atom of oxygen gas, electrically united together. We have seen how these may be electrically separated, and the molecule split up

into its two constituent gases (page 113). Each atom of gas, or of any other matter, we believe to be merely a crowd of corpuscles surrounded by an envelope of positive electricity. Each of these corpuscles is, according to our creed, a unit of negative electricity with an amount of bound ether attached to it. The unit of negative electricity itself we believe to be a "vortex ring" of ether. We therefore reduce the universe to ether, but we can go no further. The problem still remains—What is the ether?

The late Lord Salisbury wittily remarked that the ether was the nominative case of the verb "to vibrate." This is really the only one thing we do know about the ether; that it can vibrate, or undulate. Some years ago Lord Kelvin said, "It is scarcely possible to doubt the arrival of a complete theory of matter in which all its properties will be seen to be merely attributes of motion."

The motion or vibration of the air produces the sensation of sound within our sensoriums. There is no sound apart from sensation; the deaf man hears no sound although the air vibrates around him. The motion of the ether produces the sensation of vision within us. There is no visible light apart from sensation; the ether waves fall upon a blind man, but there is no vision. If a man had the misfortune to be stone deaf and blind, the world would be dark and silent, and so on.

Having in imagination resolved the universe to mere manifestations of the ether, or of electricity if we prefer to call it so, and finding that we can go no further, we may return to consider the manifestations of electrical phenomena in matter. It is

interesting, in passing, to note that this ether creed was pratically held by Newton two centuries ago. He suggested that the whole frame of nature was nothing but various contextures of some certain etherial spirits or vapours, condensed and wrought into various forms, at first by the immediate hand of the Creator, and ever after by the power of nature.

One of our leading scientists recently remarked, when replying to a toast on behalf of Electricity, that to the old questions and answers—"What is mind? No matter." "What is matter? Never mind."—We might now add, "What is the difference between electricity and matter? It is immaterial."

Throughout the preceding pages we have pictured currents of electricity flowing along wires and supplying energy to electric lamps, electro-motors, &c. What, then, is the present scientific conception of an electric current? An electric current is believed to be nothing more nor less than a mere "handing along" of a corpuscle from one atom to another; this taking place between a myriad of atoms simultaneously. There is a game which I have seen children play, and which may serve as an analogy of this process. The children stand in a long row, and at one end of the row is placed a heap of objects—say, a large number of pennies. At a given signal the children pass the coins along from one to the other, till they reach the other end of the row where they are deposited in a heap. No child is allowed to accept a coin till he or she has passed on the previous one. Another row of the same number of

children stands parallel to the first row, and these are also provided with an exactly similar number of pennies. The game being, of course, a battle royal between the two parallel rows as to which row can transmit the whole of the coins in this fashion from the one end of their line to the other in the shortest space of time. Only one row of children concerns us in our analogy, and we picture the little ones as representing the atoms in a length of metal wire. Each atom passes on a corpuscle to its neighbour and accepts another corpuscle from the neighbour on its other side. For the sake of analogy we start the game with each child having one coin in his or her hand, so that the moment the signal is given, representing the closing of the electric circuit, a complete transfer commences simultaneously all along the line. Instead of having a heap of coins at one end, we might arrange the children in a circle and give them one coin each, so that the coins would pass round and round the circle. This is what we understand by a complete electric circuit; a battery or a dynamo acting as a pump in the circuit. We may break the complete circuit and then there can be no passing on of corpuscles. The atoms try to pass their corpuscles along, but the break acts as a barrier. On testing the electrical condition of the ends of the severed wire we do find a small difference of potential.

The first arrangement of the children's game, in which we had the children standing in a row, is somewhat analogous to an earth circuit in electrical affairs. The first child kept picking up coins, passing them along, and the last child deposited the coins in

a heap as they were received. We therefore imagine the first atom at the one end of a wire, which is dipping into the earth, to be helping itself to corpuscles one at a time, passing them along, and the last atom at the other end of the wire depositing these corpuscles in the earth. There is, of course, a battery or a dynamo again acting as a pump.

According to Professor J. J. Thomson, of Cambridge, we may imagine the corpuscles free to roam about between the atoms of a metal. This gives us a somewhat different conception, for here we picture the corpuscles moving through among the atoms, just as water may pass through a sponge. However, the theory of the corpuscles being handed on is helpful, and before leaving it I would apply it to one other point.

While we are watching the children passing the coins along, we notice two or three little folk at one part of the row who cannot manage the passing very well. In the pressure of the game the smallest children get excited or agitated, and in our electric circuit the small conductor—say, the filament of carbon in our lamps—becomes molecularly agitated, and therefore very sensibly heated. This analogy, however, like all other analogies, must not be carried too far. We must not fail to keep in mind the fact that these corpuscles which the atoms hand along the wire are not particles of matter as we understand matter; they are only the units of negative electricity with their bound ether, and it requires a great crowd of them to form one infinitesimally small atom of matter. The greater ease with which the atoms of any substance can pass a corpuscle

along, the better electrical conductor is that substance. The metals are all good conductors, but even the different metals vary to a considerable extent in conductivity.

What then do we suppose to take place when an electric current is passed through a liquid conductor? We cannot revert to our analogy of the children's game, for in a liquid the molecules with their constituent atoms are in a somewhat unstable condition. The molecules are, as we have already seen, composed of electro-positive and electro-negative atoms, and in a liquid some of these atoms are constantly breaking away from one molecule and going over to another. Because of the roving or wandering propensities of these atoms Faraday christened them "ions." This is the natural condition of the liquid, but when we place the wires from a battery in the liquid the positive electrode attracts all the electro-negative atoms or ions, while the negative electrode attracts all the electro-positive atoms. In the case of pure water, by which we mean water free from all trace of chemicals, we do not find these roving atoms. If, however, there are any natural salts in the water, or, better still, if we add a little sulphuric or other acid, we immediately set some atoms of hydrogen and oxygen free to wander about. This is the meaning of what was said in connection with our inability to decompose chemically pure water (page 113). A molecule of water is, we know, composed of two electro-positive atoms of hydrogen gas and one electro-negative atom of oxygen gas, and we therefore find twice the volume of hydrogen collecting at the negative or leading-

out electrode, as we find oxygen at the positive or leading-in electrode.

We must be careful not to confuse these ions or wandering atoms with the corpuscles previously spoken of. The ions are minute particles (atoms) of ordinary matter, whereas the corpuscles are merely units of negative electricity with some bound ether attached. We therefore see that the conduction of electricity through a liquid is quite different from the conduction of electricity through a solid. In solids the atoms are not free to move, so they pass corpuscles along from one to the other. In liquids the atoms are able to rove about, and they carry the electric charge themselves from one electrode to the other. It is only at the two electrodes that the chemical action is apparent.

What about the action in a battery cell? It is exactly the same chemical action, the only difference being that in the electrolytic cell, or decomposing apparatus, we supply the two electrodes with a difference of electric potential by means of some outside source of electricity, whereas in the battery cell we use two different metals which are naturally at a difference of electric potential.

There are many other interesting points connected with the science of electro-chemistry, but sufficient detail has been given to show that the conduction of electricity through a liquid electrolyte is of quite a different nature from the conduction of a current through a metal wire. In the latter there is no chemical disturbance, the atoms merely passing on one corpuscle or unit of negative electricity and simultaneously accepting another. In the case of liquid

conduction there is always a chemical disturbance and readjustment of atoms.

When electricity is passed through a highly rarefied gas, such as in a vacuum tube, we then find free corpuscles flying from one electrode to the other with enormous velocity. It is just as though the corpuscles in this case were fired off by a gun from one electrode to the other. This is very similar to what we suppose an electric discharge to be.

What are our present ideas of magnetism? We believe it to be a force developed in the ether at right angles to the moving corpuscles. Whenever corpuscles are quickly handed along a wire we find an ether disturbance or magnetic field around it, and this force tends to turn a magnetic needle, causing it to take up a position at right angles to the wire. This is illustrated at page 18.

By means of this electrotonic theory, which we have been considering at some length, we think of light and other radiations as being disturbances set up in the surrounding ether by a change in the motions of the corpuscles.

The layman on hearing of corpuscles for the first time might quite naturally ask if these are merely imaginations of the mind. He is surprised to learn that the physicist has measured the speed of a corpuscle, the relation of the electric charge on a corpuscle to its mass, and he has even determined the mass of a corpuscle. It has been found that the corpuscles are bodies a thousand times smaller than the smallest atom of matter. It makes no difference from what kind of matter these corpuscles

are taken; they are all alike in nature and size. The atom of matter has its substance determined by the grouping together of various numbers of these corpuscles within its envelope of positive electricity.

We have been dealing with invisible molecules, atoms, corpuscles, and ether, and to do so we have to bestir our imaginative powers in order to enter into the full spirit of this most interesting theory. We must become familiar with such mental pictures as electric or ether waves, &c. I remember being present at a meeting of one of our more important philosophical societies, when a member got up during the discussion which followed the lecture and said that he failed to see where the waves came in.

Surely no one can to-day doubt the existence of the ether. Suppose that some person knew absolutely nothing about the air, he could not doubt its presence when shown its effect upon a windmill. We can show similar effects with the invisible ether. Referring again to the photograph of the rotating egg-shell, described on page 267, we see in this experiment an egg-shell spinning round, and it is certainly not set in motion by the air, for there is no wind. The experiment could be performed in a vacuum if desired. It is motion given to the ether which is moving the egg-shell. If we consider the metallic deposit on the egg-shell to be analogous to a coil of wire, we then picture the three-phase electric current in the fixed coils setting up a disturbance in the surrounding ether; we call it an electromagnetic effect, and this in turn induces similar

electric currents in the metal coating of the egg-shell. The whole arrangement is now analogous to an electro-motor; the fixed coil being the field magnets, and the egg being the conducting armature, but instead of conducting electric currents to the armature, we are inducing currents in it. There are practical electro-motors based upon this principle, and known as induction motors.

Another simple experiment which serves to show the presence of the ether is represented in Fig. 1, page 288. This little instrument is known as a radiometer, and consists of a very light wire cross with four small vanes or wings of aluminium, each having one side bright and the other dull black. This little windmill arrangement is placed in a partial vacuum within a glass bulb. When a lighted taper or match is brought near it, the small windmill immediately revolves. If placed in the sunlight or before a bright fire, it gathers so much speed that it is impossible to distinguish the vanes of the little windmill. The motion in this case is also produced by an ether disturbance. Ether waves, known as heat-waves or radiant heat, fall upon the comparatively few molecules of air remaining in the bulb. These have plenty of room to vibrate, and they bombard the flat surfaces of the vanes.

Surely the ether is also manifest when a magnetic needle is attracted or repelled by a neighbouring magnet, and in hundreds of different phenomena.

CHAPTER XXIV

CONCLUSION

A future possibility—Some comparisons—The remarkable growth of electrical engineering—An electrical cartoon from *Punch*

WHAT an immense stride science has made in recent years ! Not so very long ago our great-grandfathers believed light and heat to be material compounds of fire-air (oxygen) and phlogiston (hydrogen). Light was said to be richer in phlogiston than heat was supposed to be. With such theories our ancestors sought in vain to account for the different phenomena of light and heat. To-day we look out upon a world consisting solely of complex manifestations of the ether, the nature of which we cannot fathom, and yet with the aid of which we can satisfactorily explain so many mysteries of nature.

We find that the tiny atom has a very remarkable internal energy. Who knows that man may not some day tap that energy and use it as a source of power? In a tiny piece of radium or other radio-active body we see the atom disintegrating at the rate of one atom per second in a million billions of atoms, and thus giving up its energy, but as yet we see no means of hastening this process.

Science has advanced step by step; the present generation has witnessed some very long steps. It would be strange indeed if some corresponding advance had not followed in the practical applications

of science to our every-day life. There have indeed been enormous advances made in this direction. Witness a few examples.

Fifty years ago it took six months for a London merchant to receive an answer to an inquiry sent out to India. To-day he may despatch his message by electricity, and have a reply in his hands within as many hours as it formerly took months.

Our grandfathers had to go out upon a journey if they desired to speak to any one in a distant town. To-day we need not do so, for by means of electricity we may carry on conversation with people distant hundreds of miles from us.

Our ancestors looked at the great Niagara Falls, and regretted the hopeless waste of so grand a power. To-day we carry nearly one million horse-power from these falls, along stationary wires, to distant towns, and there drive factories, propel street cars, and light the streets.

Our forefathers had to despatch a man on horse-back with any urgent message. To-day we get electricity to carry our messages to ships at sea, the exact location of which we ourselves do not know.

As recently as 1840 the city of Glasgow had sedan-chairs plying for hire in her streets. To-day electricity carries the citizens about with great speed, not only through all the important streets and suburbs, but out to neighbouring towns.

It is indeed remarkable that electrical engineering has already attained to such an important position in so short a space of time. We reckon the year 1880 as the starting-point, and in this connection it is interesting to refer to a back number of *Punch*

By permission of *Bradbury, Agnew & Co., Ltd.*

"WHAT WILL HE GROW TO?"

This is a reproduction of a cartoon which appeared in *Punch* (London), 25th June, 1881. It represents King Steam and King Coal discussing Baby Electricity's chances of success in life.

(See chap. xxiv.)

(London), 25th June 1881. In the accompanying reproduction of a cartoon, published under that date, it will be seen that electrical engineering was then in its infancy. Many people doubted if it would ever advance to be of any consequence in the engineering world.

In the illustration (page 332) we see Baby Electricity busily engaged in drawing nourishment from a feeding-bottle, marked "storage of force." Over the sturdy infant stand two giants, somewhat disconcerted. The one wears a crown bearing the words "King Steam," while the other is a dusky fellow, on whose crown are the words "King Coal." The cartoon, entitled "What will he grow to?" was accompanied by a rhyme, this being an imaginary dialogue between the giants Steam and Coal. The following is a short extract :—

> "Humph. That the Prodigy? Do not think much of him.
> Rather a mannikin, eh, after all?
> Who says we're doomed to collapse at the touch of him?
> Who says his avatar heralds our fall?"

Then Steam argues that Electricity is but a child, to which Coal replies that the child has a "sort of an expression that frightens him," and Steam finally replies :—

> "If this young spark, as is fancied by Thomson,
> Turn out a true Titan—Ariel—Puck,
> Who, without mischief, will carry huge romps on,
> All I can say is, the world is in luck."

APPENDIX I

SOME INTERESTING DATES

THROUGHOUT this volume I have purposely omitted many dates of discoveries and inventions, preferring to collect these together and add them in this supplementary manner. I do not propose to give a long list of historical dates, but to confine the particulars to those facts immediately leading up to Electricity of to-day. It may be of more interest to group together those dates referring to each great application of electricity.

The Beginning

1790. Professor Galvani, of Italy, made his historical discovery with the legs of a frog.

1800. Professor Volta, of Italy, following up this experiment, discovered the chemical means of producing an electric current.

Electric Light

1802. Sir Humphry Davy (London) discovered the electric arc.

1858. Electric arc lamps used at the laying of the foundation of Westminster Bridge, London.

1880. Swan and Edison independently invented carbon filament glow lamps.

1881–82. Electric light exhibitions in Paris and London caused a panic amongst gas-shareholders.

Electric Power and Traction

1819. Hans Christian Oersted, of Denmark, discovered that an electric current in a wire affected a neighbouring magnet.

1820. Arago (France) and Davy (London) independently discovered that a piece of iron became magnetised by passing an electric current through an insulated wire surrounding it.

1831. Michael Faraday, in London, discovered that electric currents could be produced by merely moving a coil of wire in a magnetic field.

Professor Joseph Henry (U.S.A.) discovered the same important fact almost simultaneously with Faraday.

1870. Self-exciting dynamos were invented.

1879. Miniature electric railway at Berlin Exhibition.

1881. Short line of electric railway at Portrush (Ireland), and another at Lichterfelde (Germany).

1887. First successful electric street tramway at Richmond (U.S.A.).

Telegraphs

1822. A practical galvanometer invented by Schweigger.

1837. Needle telegraph (galvanometer) patented in London by Cooke and Wheatstone.

1825. The first soft iron electro-magnet invented by Sturgeon (London).

1837. Morse (U.S.A.) patented his now universal system of telegraphy, employing soft iron electro-magnets.

1838. Steinheil (Munich) discovered that an earth circuit might be used in place of a return circuit.

1858. The first Atlantic cable was laid. Shorter cables had been previously laid in the North Sea, &c.

1896. Practical wireless telegraphy was set on foot by Marconi (Italy). The practical experiments were carried out in Great Britain.

Telephones

1837. Page (U.S.A.) discovered that if an iron rod was quickly magnetised and demagnetised it emitted a sound.

1860. Reis (Germany) transmitted music and words, the latter only imperfectly.

1876. Graham Bell (U.S.A.) invented a magneto-telephone and transmitted speech.

1879. Hughes (London) invented a carbon microphone transmitter.

Appendix

Electro-chemistry

1800. Carlisle and Nicholson (Britain) decomposed water by means of Volta's pile.

1802. Davy laid the foundations of electro-chemistry.

1805. Brugnatelli (Italy) electro-gilded two silver coins.

1839. Electro-plating commenced on a practical scale.

Miscellaneous

1822. Seebeck (Berlin) discovered that an electric current could be produced by heating the junction of two dissimilar metals.

1895. Roentgen (Germany) discovered the well-known X-rays.

It is interesting to note that telegraphy, both by land and by sea, was firmly established before electric light and power were afoot commercially.

In order to fix a few of the more important electrical dates in one's mind, it may be of some assistance to note that Galvani and Volta made their pioneer discoveries in Italy, during the time of the great French Revolution.

Oersted made his important discovery of the intimate connection between electricity and magnetism during the year in which the late Queen Victoria was born (1819). This was also the first year in which a small steamer of 300 tons crossed the Atlantic.

Practical electric telegraphs were invented, both

in Britain and America, during the year in which Queen Victoria ascended the throne (1837). The telegraphs did not carry public messages till King Edward VII. was several years of age.

The year 1880 stands out very prominently as the starting-point of electrical engineering. For more recent discoveries one usually has personal recollections of contemporary events.

VOLTA 1745-1827

APPENDIX II

SOME REMARKS ON THE ABSOLUTE UNITS

THE majority of readers will not want to trouble about the subject of absolute units, being content to know that these have been scientifically determined, and that the subject is a difficult one. There may be some readers, however, who would like to know a little more of the subject. I therefore add the following few remarks for the use of any such readers.

When the British Association Committee were set the task of defining units for electrical measurements, it was apparent that this could not be done unless some universal foundation was agreed upon. The committee therefore selected three fundamental physical units—a definite length, a definite mass, and a definite interval of time. After a long discussion they decided to adopt the centimetre as the unit of length, the gramme as the unit of mass, and the mean solar second as the unit of time. With these as a foundation, the committee determined all the physical units we employ in science, including those of electricity. The units thus derived are said to be on the centimetre-gramme-second system, or briefly the C.G.S. system.

For instance, the C.G.S. unit of *force* was called the *dyne*, and is defined as that force which, acting upon a gramme for a second, generates a velocity of a

centimetre per second. Then, again, in order to measure the strength of magnetic fields, it was arranged that the unit magnetic pole (the pole of unit strength) should be that which repels an equal pole placed at unit distance (one centimetre) with unit force (one dyne). The electrical units were then defined in terms of these units.

We can measure the strength of an electric current by its electro-magnetic effect, or, in other words, by the force of attraction exerted between it and a magnet placed near it. The unit of current strength is therefore defined in the following statement. If a unit magnetic pole be placed at the centre of a circle whose radius is one centimetre (unit length), and we then bend a piece of wire one centimetre in length to form an arc of this circle, the current which, when flowing through this wire, would act upon the unit magnetic pole with a force of one dyne is to be reckoned as the unit of current.

The unit of electric pressure or electro-motive force (E.M.F.) is then defined in the following manner. If the E.M.F. between two points in a circuit be such that unit current flowing for unit time does unit work between these points, this E.M.F. is taken as the unit of electro-motive force.

Then the unit of electrical resistance is defined as that resistance through which unit electro-motive force gives unit current.

These three electrical units are called absolute units because they are not merely ratios, and are quite independent of any artificial standard. It is natural for the layman to inquire by what means the scientist is able to realise those units, for it is quite apparent

that they have been theoretically defined. He has the great natural force of gravitation to which he can refer all his measurements; but this entails laborious mathematical calculations, not only beyond the scope of the present volume, but forming a subject which is only dealt with in the advanced science text-books.

I wish merely to remark, in passing, that in another method of realising these absolute units the scientist makes use of the natural magnetic field of the earth. He spins a simple closed coil of wire in a vertical position, whereupon an electric current is induced in the coil owing to its cutting the lines of force of the earth. We may look upon this simple coil as the armature of a dynamo, the field magnet of which is the earth. One is at first surprised to learn that a current of electricity is so easily generated; simply turning round a coil of wire in a vertical position. I believe it would be quite true to assert that, even when a boy turns round with an iron hoop in his hand, there is an electric current induced in the hoop; but it would, of course, be impossible to detect so small a current. I remember, however, on one occasion having an opportunity of using an extremely sensitive testing instrument. Picking up an ordinary coil of wire, I connected its loose ends to the wires of the testing instrument, and each time I moved the coil, by turning my wrist, there was a distinct deflection shown by the instrument, proving that an electric current was induced in the coil of wire each time it was turned round in the magnetic field of the earth.

I have merely indicated in a very general way the method of procedure in the realisation of the absolute units. Only the advanced mathematician is capable

of making the necessary deductions required in determining these. It goes without saying, that the scientific instrument maker is not going to make any such attempts by which to graduate his measuring instruments. He may be aware that the practical unit of resistance (the ohm) is one hundred million times the value of the absolute unit scientifically determined, but that does not concern him in his practical work. It is sufficient for him to know that the value of the ohm has been determined by careful experiments made by an International Commission, and that it has been found to be equal to the resistance offered by a column of mercury of certain dimensions (one square millimetre in section, and 106.3 centimetres long), and at a temperature of zero Centigrade.

The instrument maker need not even know that the practical unit of electric pressure (the volt) is equal to ten million absolute units, for the Board of Trade standardise a special battery cell, which gives a definite voltage. Neither does it concern him that the practical unit of current (the ampere) is one-tenth of the absolute unit, for if he has means of measuring a pressure of one volt, and also a resistance of one ohm, he knows by Ohm's law that the electric current which a pressure of one volt can send through a resistance of one ohm is at the rate of flow of one ampere.

It may occur to some readers that the scientific instrument maker is no more independent than the manufacturer of yard measures, seeing that the instrument maker does not concern himself with the scientifically determined absolute units. But if we consider the relative positions of the two makers, we

shall see that the electrical instrument maker is much more independent. If the manufacturer of yard measures is deprived of his standard of reference he is helpless. If the electrical instrument maker is deprived of his standard of resistance, he can easily make another column of mercury of the required dimensions to give him the resistance of one ohm, and from that he can make up any suitable resistance to work from.

It might be suggested that the absolute units, being based upon the centimetre, the gramme, and the second, are resting upon an artificial foundation; but this is not so, for these fundamental units have been scientifically defined. The metre may be defined in the following manner. Taking the distance from the equator to the pole, or in other words a quadrant of the meridian, and measuring this as along the surface of still water, the metre is one ten-millionth part of this large arc. The centimetre is, of course, the one-hundredth part of the metre. The gramme, which is the unit of mass, is then taken as the weight of a cubic centimetre of distilled water at its point of maximum density, which is about four degrees Centigrade scale.

The unit of time, the second, is measured by clocks and chronometers, but these are checked daily by astronomical observations. The transit telescope is in truth a clock which never varies. The time between two successive transits of a star gives us the time of the rotation of the earth upon its axis, and it is upon the uniformity of this rotation that the preservation of our standards of time depend.

These few remarks may serve to give readers, in-

terested in the subject, a very general idea of the meaning of absolute units, but it will be clear that to obtain a definite and detailed knowledge of the subject would necessitate considerable previous knowledge of mathematics.

INDEX

ABSOLUTE units, 273, 339
Accumulators, 72, 129
Agriculture, 181
Alternating current, 34, 311
Aluminium, production of, 107, 120
Ammeter, 289
Ampere, the, 280, 284, 309, 342
Ampère, Professor, 196, 280
Anti-coherers, 223
Arc, the electric, 77, 99
Arc furnace, 106
Arc lamps, 78
Armstrong's machine, 162, 264
Atmospheric electricity, 162
Atom, the, 319
Aurora borealis, 140
Aurora australis, 143

BATHS, electric, 105, 297
Battery, 20, 111, 124, 327
Bell, electric, 166
Brake, magnetic, 52
B.T.U. *See* Unit, Board of Trade

CATHODE rays, 313
Cautery, electric, 301
Cavendish, Hon. Henry, 130
Cells, dry, 127
Chemical effects of current, 111
Chemical union, 320
Circuit, complete, 27
Clocks, electric, 174
Coherers, 221
Cohesion, 321
Condensers, 214, 309
Conduit system (tramways), 68
Corpuscles, 318, 325, 328
Coulomb, the, 287

DAVY, Sir Humphry, 77, 86, 99, 112, 116
Decomposition of water, 113, 321, 326
De Forest, wireless telegraphy, 228
Diamonds, production of, 108
Duplex telegraphy, 193
Dynamo, alternating, 34
Dynamo, direct current, 35, 39
Dynamos, 30, 41, 277

EARTH circuit, 202, 324
Electric current, 21, 323
Electrolysis, 118, 121
Electrolytic furnace, 107

Index

Electro-magnet, 25
Electromobile, 71
Electro-negative, 319
Electrons. *See* Corpuscles
Electro-plating, 123, 306, 337
Electro-positive, 319
Electro-refining, 122
Electrotonic theory, 328
Ether, the, 317, 322, 329

FARADAY, Michael, 31, 77, 118
Filament, carbon, 88
Finsen lamp, 295
Fire-alarms, 169
Flame arc, 84
Fluorescent screen, 298, 314
Franklin, Benjamin, 145
Furnace, electric, 105

GALVANI, Professor, 19, 337
Galvanometer, mirror, 209
Galvanometer, needle, 275
Gilbert, Dr. William, 17
Gravitation, 321

HERTZ, Dr., 218, 235
Heating and cooking, 98

INDICATORS, 168
Induction coils, 266, 308
Insulation, 26

KELVIN, Lord, 209, 211
Kilowatt, the, 282

LAMP, arc, 78
Lamp, glow, 87
Lamp, mercury vapour, 96
Lamp, Nernst, 96
Launches, electric, 73
Lightning, 145, 154
Lightning protectors, 50, 157
Lupus cure, 295

MAGNETIC poles, 23
Magnetism, nature of, 328
Marconi, 221, 227
Meter, supply, 292
Molecule, the, 320
Motor-car, electric. *See* Electromobile
Motor, electric, 29, 45
Motor reversing, 48

NEGATIVE electricity, 303, 319
Niagara, 75

OCEAN cables, 204
Oersted, Hans Christian, 22, 337
Ohm, the, 283, 342
Ozone, 161, 300

PILE, voltaic, 20, 111
Positive electricity, 303, 319
Preece's wireless telegraphy, 236
Pressure, electric, 56, 59, 61, 277
Propeller governor, 179
Pulsating current, 311
Pyrometer, 137

QUADRUPLEX telegraphy, 192

Index

RADIATORS, 104
Radiometer, 330
Radium, 331
Railway signalling, 177, 199
Relays, 194, 257
Resinous electricity, 395 *n.*
Resistance coils, 47
Resistance, electric, 100, 278, 282
Resistance furnace, 106
Roentgen, Professor, 313, 337
Roentgen rays. *See* X-rays

ST. ELMO'S Fire, 161
Searchlight, 81, 217
Secondary cells. *See* Accumulators
Seebeck, Professor, 132
Shock, electric, 66
Siphon recorder, 210
Smoke rings, 151, 318
Sound, propagation of, 239
Storage battery. *See* Accumulators
Surface contact system (tramways), 69
Switch, automatic, 49

TELEGRAPH, Morse, 185, 195
Telegraph, needle, 196
Telegraph repeater, 194
Telephones, 239
Telephone exchanges, 248, 254
Therapeutic effects, 105, 294
Thermo-electricity, 133
Thermometer, electric, 134
Thermo-pile, 133
Thomson, Sir William. *See* Kelvin
Thunder, 152, 159
Thunderbolt, 149
Tools, electric, 74
Transformers, 59, 101

UNIT, Board of Trade, 285, 287, 291
Unit of negative electricity, 318

VACUUM tubes, 142, 159, 312
Vitreous electricity, 305 *n.*
Volt, the, 276, 284, 309, 342
Volta, Professor, 20, 276, 337
Voltage. *See* Pressure
Voltmeter, 289

WATT, the, 282
Welding, electric, 107
Wireless telegraphy, 215
Wireless telephony, 237, 261

X-RAYS, 296, 298, 312

Printed by BALLANTYNE, HANSON & Co.
Edinburgh & London

WORKS BY C. J. CORNISH

THE NATURALIST ON THE THAMES. With Thirty-eight Illustrations. Demy 8vo. 7s. 6d.

"Will give great delight to any lover of natural history. . . . It is a most fascinating volume, and is illustrated in a manner worthy of the text."—*Scotsman.*

"From the first page to the last there is not a single page which the reader would not wrong himself by skipping."—*Standard.*

ANIMALS OF TO-DAY: Their Life and Conversation. With Illustrations from Photographs by C. REID, of Wishaw. Crown 8vo. 6s.

"Quite one of the brightest books of popular natural history which have appeared in recent years is Mr. Cornish's fascinating studies of 'Animals of To-Day.'"—*Leeds Mercury.*

NIGHTS WITH AN OLD GUNNER, and other Studies of Wild Life. With Sixteen Illustrations. 6s.

"Cannot fail to be interesting to any lover of wild nature. The illustrations are numerous and excellent."—*Pall Mall Gazette.*

ANIMALS AT WORK AND PLAY: Their Emotions and Activities. Illustrated from Photographs by GAMBIER BOLTON, F.Z.S., and others, and from Drawings. Third Edition. 6s.

"Such a book as Mr. Cornish's shows how much there is to repay the intelligent observer of Nature."—*Times.*

"Good as the former books were, we are disposed to think that this is even better still."—*Spectator.*

WILD ENGLAND OF TO-DAY, and the Wild Life in It. Illustrated with Original Drawings by LANCELOT SPEED, and from Photographs. Third Edition. 6s.

"Those of us who are left in town in the dull days will seem, in reading these pages, to sniff the fresh sea-breezes, to hear the cries of the sea-bird and the songs of the wood-bird, to be conscious of the murmuring stream and waving forests, and all the wild life that is therein."—*St. James's Gazette.*

LIFE AT THE ZOO. Notes and Traditions of the Regent's Park Gardens. Illustrated from Photographs by GAMBIER BOLTON, F.Z.S. Fifth Edition. 6s.

"Every lover of animals will find abundance of attraction and entertainment in Mr. Cornish's delightful volume."—*Times.*

THE ISLE OF WIGHT. With Four Etchings and many other Illustrations. Super Royal 8vo. 3s. 6d. net.

THE NEW FOREST. With Four Etchings and many other Illustrations. Super Royal 8vo. 3s. 6d. net.

Also a POCKET EDITION, 16mo, cloth, 2s. net; leather, 3s. net.

SEELEY & CO., LTD., 38 GREAT RUSSELL STREET

A Catalogue of Books on Art History, and General Literature Published by Seeley & Co Ltd 38 Great Russell Street, London

Some of the Contents

Events of Our Own Times Series . . 6
Miniature Library of Devotion . . . 10
Portfolio Monographs 12
Seeley's Illustrated Pocket Library . . 14
Writers and Painters of Eighteenth Century 16

The Publishers will be pleased to post their complete Catalogue or their Illustrated Miniature Catalogue on receipt of a post-card

CATALOGUE OF BOOKS

Arranged alphabetically under the names of Authors and Series

ABBOTT, Rev. E. A., D.D.

English Lessons for English People. Crown 8vo, 4s. 6d.

Hints on Home Teaching. Crown 8vo, 3s.

How to Parse. An English Grammar. Fcap. 8vo, 3s. 6d.

How to Tell the Parts of Speech. An Introduction to English Grammar. Fcap. 8vo, 2s.

How to Write Clearly. Rules and Exercises on English Composition. Crown 8vo, 1s. 6d.

Latin Gate, The. A First Latin Translation Book. Crown 8vo, 3s. 6d.

Via Latina. A First Latin Grammar. Crown 8vo, 3s. 6d.

ADY, Mrs. *See* CARTWRIGHT, JULIA.

ANDERSON, Prof. W.

Japanese Wood Engravings. Coloured Illustrations. Super-royal 8vo, sewed, 2s. 6d. nett; half-linen, 3s. 6d. nett.

ARMSTRONG, Sir WALTER.

The Art of Velazquez. Illustrated. Super-royal 8vo, sewed, 3s. 6d. nett.

The Life of Velazquez. Illustrated. Super-royal 8vo, sewed, 3s. 6d. nett.

Velazquez. A Study of his Life and Art. With Eight Copper Plates and many minor Illustrations. Super-royal 8vo, cloth, 9s. nett.

Thomas Gainsborough. Illustrated. Super-royal 8vo, half-linen, 3s. 6d. nett.

Notes on the National Gallery. 1s.

The Peel Collection and the Dutch School of Painting. With many Illustrations in Photogravure and Half-tone. Super-royal 8vo, sewed, 5s. nett; cloth, 7s. nett.

W. Q. Orchardson. Super-royal 8vo, sewed, 2s. 6d.; half-linen, 3s. 6d. nett.

Scottish Painters. With Etchings and Vignettes. Imperial 4to, 21s.

ATKINSON, J. BEAVINGTON.

Schools of Modern Art in Germany. Fourteen Etchings, and many Woodcuts. Imperial 4to, £1, 11s. 6d.

BEDFORD, Rev. W. K. R.

Malta and the Knights Hospitallers. Super-royal 8vo, sewed, 2s. 6d. nett; half-linen, 3s. 6d. nett.

BENHAM, Rev. Canon.

Mediæval London. With a Frontispiece in Photogravure, Four Plates in Colour, and many other Illustrations. Super-royal 8vo, sewed, 5s. nett; cloth, gilt top, 7s. nett.

Old St. Paul's Cathedral. With a Frontispiece in Photogravure, Four Plates printed in Colour, and many other Illustrations. Super-royal 8vo, sewed, 5s. nett, or cloth, gilt top, 7s. nett.

BICKERSTETH, Rev. E.

Family Prayers for Six Weeks. Crown 8vo, 3s. 6d.

A Companion to the Holy Communion. 32mo, cloth, 1s.; roan, 2s.

BINYON, LAURENCE.

Thomas Girtin: His Life and Works. An Essay. With Twenty-one Reproductions in Autotype. Imperial 4to, £2, 2s. nett.

Dutch Etchers of the Seventeenth Century. Illustrated. Super-royal 8vo, sewed, 2s. 6d.; half-linen, 3s. 6d. nett.

John Crome and John Sell Cotman. Illustrated. Super-royal 8vo, sewed, 3s. 6d. nett.

BIRCH, G. H.

London on Thames in Bygone Days. With Four Plates printed in Colour and many other Illustrations. Super-royal 8vo, sewed, 5s. nett; cloth, gilt top, 7s. nett.

BRIDGES, Rev. C.

An Exposition of Psalm CXIX. Crown 8vo, 5s.

CAMERON, D. Y.

Six Etchings by D. Y. CAMERON and WILLIAM STRANG. With Biographical Notes. Imperial 4to, 6s. nett.

CARTWRIGHT, JULIA.

Jules Bastien-Lepage. Super-royal 8vo, sewed, 2s. 6d.; cloth, 3s. 6d.

Sacharissa. Some Account of Dorothy Sidney, Countess of Sunderland, her Family and Friends. With Five Portraits. Demy 8vo, 7s. 6d.

Madame: Memoirs of Henrietta, daughter of Charles I. and Duchess of Orleans. With Five Portraits. Demy 8vo, 7s. 6d.

Raphael in Rome. Illustrated. Super-royal 8vo, sewed, 2s. 6d.; half-linen, 3s. 6d. nett.

The Early Work of Raphael. Illustrated. Super-royal 8vo, sewed, 2s. 6d.; half-linen, 3s. 6d.

Raphael: A Study of his Life and Work. With Eight Copper Plates and many other Illustrations. Super-royal 8vo, 7s. 6d. nett.

CESARESCO, The Countess MARTINENGO.

The Liberation of Italy. With Portraits on Copper. Crown 8vo, 5s.

CHORAL SERVICE-BOOK FOR PARISH CHURCHES, THE.
Compiled and Edited by J. W. ELLIOTT, Organist and Choirmaster of St. Mark's, Hamilton Terrace, London. With some Practical Counsels taken by permission from "Notes on the Church Service," by Bishop WALSHAM HOW.

A. Royal 8vo, sewed, 1s.; cloth, 1s. 6d.
B. 16mo, sewed, 6d.; cloth, 8d.

The following portions may be had separately:—

The Ferial and Festal Responses and the Litany. Arranged by J. W. ELLIOTT. Sewed, 4d.

The Communion Service, Kyrie, Credo, Sanctus, and Gloria in Excelsis. Set to Music by Dr. J. NAYLOR, Organist of York Minster. Sewed, 4d.

CHURCH, A. H., F.R.S.

Josiah Wedgwood, Master Potter. With many Illustrations. Super-royal 8vo, sewed, 5s. nett; cloth, 7s. nett.

The Chemistry of Paints and Painting. Third Edition. Crown 8vo, 6s.

CHURCH, Rev. A. J.

The Laureate's Country. Scenes connected with the Life of Alfred, Lord Tennyson. With Fifteen Copper Plates and numerous Vignettes by E. HULL. Imperial 4to, 21s.

Nicias, and the Sicilian Expedition. Crown 8vo, 1s. 6d.

For other books by Professor CHURCH see Complete Catalogue.

CLARK, J. W., M.A.

Cambridge. With many Illustrations by A. BRUNET-DEBAINES and H. TOUSSAINT. Crown 8vo, 3s. 6d.

CLEMENT, CHARLES.

Michel Angelo, Lionardo da Vinci, and Raphael. With Eight Illustrations on Copper. Crown 8vo, 10s. 6d.

CONWAY, Sir W. M.

The Early Flemish Artists, and their Predecessors on the Lower Rhine. With many Illustrations. Crown 8vo, 7s. 6d.

CORNISH, C. J.

Animals at Work and Play: Their Activities and Emotions. With Twelve Illustrations. Second Edition. Crown 8vo, 6s.

Animals of To-day: Their Life and Conversation. With Illustrations from Photographs by C. REID of Wishaw. Crown 8vo, 6s.

The Isle of Wight. Illustrated. Super-royal 8vo, sewed, 2s. 6d. nett; half-linen, 3s. 6d. nett.

Life at the Zoo. Notes and Traditions of the Regent's Park Gardens. Illustrated from Photographs by GAMBIER BOLTON. Fifth Edition. Crown 8vo, 6s.

The Naturalist on the Thames. With many Illustrations. Demy 8vo, 7s. 6d.

The New Forest. Super-royal 8vo, sewed, 2s. 6d. nett; half-linen, 3s. 6d. nett.

The New Forest and the Isle of Wight. With Eight Plates and many other Illustrations. Super-royal 8vo, 7s. 6d. nett.

Nights with an Old Gunner, and other Studies of Wild Life. With Sixteen Illustrations by LANCELOT SPEED, CHARLES WHYMPER, and from Photographs. Crown 8vo, 6s.

Wild England of To-day and the Wild Life in it. With Sixteen Illustrations from Drawings by LANCELOT SPEED, and from Photographs. Crown 8vo, 6s.

CORROYER, E.

Gothic Architecture. Edited by Sir WALTER ARMSTRONG. With over Two Hundred Illustrations. Crown 8vo, 6s.

CUST, LIONEL.

The Engravings of Albert Dürer. Illustrated. Super-royal 8vo, sewed, 2s. 6d.; half-linen, 3s. 6d. nett.

Paintings and Drawings of Albert Dürer. Illustrated. Super-royal 8vo, sewed, 3s. 6d. nett.

Albrecht Dürer. A Study of his Life and Work. With Eight Copper Plates and many other Illustrations. Super-royal 8vo, 7s. 6d.

DALE, J. M.

The Clergyman's Legal Handbook and Churchwarden's Guide. Seventh Edition. Revised and brought up to date by J. S. RISLEY. 7s. 6d.

DAVENPORT, CYRIL.

Cameos. With examples in Colour and many other Illustrations. Super-royal 8vo, sewed, 5s. nett; cloth, 7s. nett.

Royal English Bookbindings. With Coloured Plates and many other Illustrations. Super-royal 8vo, sewed, 3s. 6d.; cloth, 4s. 6d.

DAWSON, Rev. E. C.

The Life of Bishop Hannington. Crown 8vo, paper boards, 2s. 6d.; or with Map and Illustrations, cloth, 3s. 6d.

DE LA BERE, K. BAGHOT.

The New Poultry Guide for British Farmers and Others. Showing the one and only way of making Farm Poultry a rent-paying industry. 1s.

DESTRÉE, O. G.

The Renaissance of Sculpture in Belgium. Illustrated. Super-royal 8vo, sewed, 2s. 6d. nett; half-linen, 3s. 6d. nett.

DODGSON, CAMPBELL.

The Etchings of Rembrandt. By P. G. HAMERTON, with an Annotated Catalogue of all the Etchings by CAMPBELL DODGSON. With Fifty Facsimile Reproductions of the most notable Etchings in Photogravure. Only 250 copies printed, 225 for sale, numbered 1–225. Double crown folio (20=15 ins.), £5, 5s. nett.

EARDLEY, WILMOT, Rear-Admiral S.

Our Fleet To-day and its Development during the last Half Century. With many Illustrations. Crown 8vo, 5s.

ELSON, ARTHUR.

A Critical History of Opera. With Photogravure Frontispiece. Crown 8vo, cloth, gilt top, 5s. nett.

ELSON, LOUIS C.

Great Composers and their Work. With Photogravure Frontispiece. Crown 8vo, cloth, gilt top, 5s. nett.

Seeley & Co Limited

EVENTS OF OUR OWN TIMES

Crown 8vo. With Illustrations, 5s. each.

The War in the Crimea. By General Sir E. HAMLEY, K.C.B. With Copper Plates and other Illustrations. 5s.

The Indian Mutiny. By Colonel MALLESON, C.S.I. With Copper Plates and other Illustrations. 5s.

The Afghan Wars, 1839-42, and 1878-80. By ARCHIBALD FORBES. With Portraits and Plans. 5s.

Our Fleet To-Day and its Development during the last Half Century. By Rear-Admiral S. EARDLEY WILMOT. With many Illustrations. 5s.

The Refounding of the German Empire. By Colonel MALLESON, C.S.I. With Portrait and Plans. 5s.

The Liberation of Italy. By the Countess MARTINENGO CESARESCO. With Portraits on Copper. 5s.

Africa in the Nineteenth Century. By EDGAR SANDERSON, M.A. With Portraits and a Map. 5s.

The War in the Peninsula. By A. INNES SHAND. With Portraits and Plans. 5s.

FARNELL, G. S.

Greek Conditional and Relative Sentences. Crown 8vo, 1s. 6d.

FERRAR, NICHOLAS.

The Story Books of Little Gidding: Being the Religious Dialogues recited in the Great Room at Little Gidding Hall, 1631–2. From the Original Manuscript of NICHOLAS FERRAR. With an Introduction by E. CRUWYS SHARLAND, and several Illustrations. Crown 8vo, 6s.

FLAXMAN, JOHN.

Flaxman's Classical Outlines. Homer's Iliad — Homer's Odyssey — Æschylus' Tragedies—Hesiod's Works and Days and Theogony. Four Parts, Cloth, 4s. 6d. each; or complete in one vol., cloth, 14s.

FLETCHER, W. Y.

Bookbinding in England and France. Seventeen Coloured Plates and many other Illustrations. Super-royal 8vo, 7s. 6d. nett.

Bookbinding in France. Coloured Plates. Super-royal, sewed, 2s. 6d. nett; half-linen, 3s. 6d. nett.

FORBES, ARCHIBALD.

The Afghan Wars of 1839-1842 and 1878-1880. With Four Portraits on Copper, and Maps and Plans. Crown 8vo, 5s.

FRY, ROGER.

Discourses Delivered to the Students of the Royal Academy by Sir Joshua Reynolds. With an Introduction and Notes by ROGER FRY. With Thirty-three Illustrations. Square Crown 8vo, 7s. 6d. nett.

GARDNER, J. STARKIE.

Armour in England. With Eight Coloured Plates and many other Illustrations. Super-royal 8vo, sewed, 3s. 6d. nett.

Foreign Armour in England. With Eight Coloured Plates and many other Illustrations. Super-royal 8vo, sewed, 3s. 6d. nett.

Armour in England. With Sixteen Coloured Plates and many other Illustrations. The two parts in one volume. Super-royal 8vo, cloth, gilt top, 9s. nett.

GARNETT, R., LL.D.

William Blake, Painter and Poet. Illustrated. Super-royal 8vo, sewed, 2s. 6d. nett; cloth, 3s. 6d. nett.

Richmond on Thames. Illustrated. Super-royal 8vo, sewed, 3s. 6d. nett.

GIBERNE, AGNES.

Beside the Waters of Comfort. Crown 8vo, 3s. 6d.

Royal Priests. 32mo, 1s.

GODLEY, A. D.

Socrates and Athenian Society in his Day. Crown 8vo, 4s. 6d.

GRAHAME, GEORGE.

Claude Lorrain. Illustrated. Super-royal 8vo, 2s. 6d. nett; half-linen, 3s. 6d. nett.

GRINDON, LEO.

Lancashire. Brief Historical and Descriptive Notes. With many Illustrations by A. Brunet-Debaines, H. Toussaint, R. Kent Thomas, and others. Crown 8vo, 6s.

HADOW, W. H.

A Croatian Composer. Notes toward the Study of Joseph Haydn. Crown 8vo, 2s. 6d. nett.

Studies in Modern Music. First Series. Berlioz, Schumann, Wagner. With an Essay on Music and Musical Criticism. With Five Portraits. Crown 8vo, 7s. 6d.

Studies in Modern Music. Second Series. Chopin, Dvoràk, Brahms. With an Essay on Musical Form. With Four Portraits. Crown 8vo, 7s. 6d.

HAMERTON, Mrs.

Philip Gilbert Hamerton. Autobiography (1834–1858), and Memoir by his Wife (1858–1894). With a Portrait. Demy 8vo, 16s.

HAMERTON, P. G.

Chapters on Animals. With 20 etchings by Bodmer and Veyrassat. Post 8vo, cloth, 12s. 6d.
Cheaper Edition, with Eight Etchings. Cloth, 5s.

The Etchings of Rembrandt, and Dutch Etchers of the Seventeenth Century. By P. G. Hamerton and Laurence Binyon. With Eight Copper Plates and many other Illustrations. Super-royal 8vo, 7s. 6d. nett.

The Etchings of Rembrandt, with an Annotated Catalogue of all the Etchings by Campbell Dodgson. With Fifty Facsimile Reproductions of the most notable Etchings in Photogravure. Only 250 copies printed, 225 for sale, numbered 1–225. Double crown folio (20×15 ins.), £5, 5s. nett.

Imagination in Landscape Painting. With many Illustrations. Crown 8vo, 6s.

Modern Frenchmen. Five Biographies — Victor Jacquemont, Henri Perreyve, François Rude, Jean Jacques Ampère, Henri Regnault. Crown 8vo, 7s. 6d.

The Mount. Narrative of a Visit to the Site of a Gaulish City on Mount Beuvray. With a Description of the neighbouring City of Autun. Crown 8vo, 3s. 6d.

Round my House. Notes on Rural Life in Peace and War. Crown 8vo, 3s. 6d.

The Sylvan Year. Leaves from the Note-Book of Raoul Dubois. With Eight Etchings by the Author and other Artists. Crown 8vo, 5s.

HAMLEY, Gen. Sir E.

The War in the Crimea. With Copper Plates and other Illustrations. Crown 8vo, 5s.
Cheaper Edition, paper cover. Demy 8vo, 6d. nett.

HARTLEY, C. GASQUOINE.

Pictures in the Tate Gallery. With Twenty Reproductions. Demy 4to, 12s. 6d. nett.
Also an Edition de Luxe on Dutch Hand-made Paper, limited to 100 numbered copies. Only a few copies left. Price 25s. nett.

HEATON, Mrs. C.

Life of Albert Dürer. With Sixteen Illustrations. 8vo, 10s. 6d.

HEBERT, CHARLES, D.D.

The Lord's Supper. Uninspired Teaching. Clement of Rome to Canon Liddon, A.D. 74 to 1875. In two vols., 7s. 6d. (reduced from £1, 8s.).

HERBERT, GEORGE.

The Temple. Sacred Poems and Ejaculations. The Text reprinted from the First Edition. With Seventy-six Illustrations after ALBERT DÜRER, HOLBEIN, and other Masters. Crown 8vo, cloth, 2s. nett; leather, 3s.; and in special yapp leather in box, 5s. nett.

HOARE, Rev. J. G.

Righteousness and Life. 16mo, 1s.

HOW, W. W.

Hannibal, and the Great War between Rome and Carthage. 2s.

HUSON, T.

Round about Helvellyn. Twenty-four Plates in Etching and Aquatint. Imperial 4to, 21s. nett. Large paper copies (50 only), £2, 12s. 6d. nett.

Round about Snowdon. Thirty Plates in Etching and Aquatint. With Notes by J. J. HISSEY. Imperial 8vo, 21s. nett. Large paper copies (75 only), £2, 12s. 6d. nett.

HUTCHINSON, Rev. H. N.

The Story of the Hills. A Popular Account of Mountains and How They were Made. With many Illustrations. Crown 8vo, 5s.

HUTTON, C. A.

Greek Terracotta Statuettes. With a Preface by A. S. MURRAY, LL.D. With Seventeen Examples printed in Colour and Thirty-six printed in Monochrome. 5s. nett; or cloth, 7s. nett.

JAMES, CAIRNS.

The Golden Reciter. With an Introduction by CAIRNS JAMES, Professor of Elocution at the Royal Academy of Music, &c. With Selections from Rudyard Kipling, Thomas Hardy, R. L. Stevenson, Seton Merriman, H. G. Wells, Christina Rossetti, Anthony Hope, Austin Dobson, Maurice Hewlett, Conan Doyle, &c. &c. Extra crown 8vo, 704 pp. Cloth, 3s. 6d., and thin paper edition in cloth with gilt edges, 5s.

JOWETT, Rev. W.

The Christian Visitor. Two Vols. Crown 8vo.

The Old Testament. 3s. 6d.
The New Testament. 3s. 6d.

JOY, BEDFORD.

A Synopsis of Roman History. Crown 8vo, 2s.

KERR, RICHARD.

Wireless Telegraphy. Popularly Explained. With Preface by Sir W. H. PREECE, K.C.B., F.R.S., and many Illustrations. Sixth Edition, Revised. Fcap. 8vo, sewed, 1s.; cloth, 1s. 6d.

LANG, ANDREW.

Oxford. New Edition. With 50 Illustrations by J. H. LORIMER, R.S.A., T. HAMILTON CRAWFORD, R.S.W., J. PENNELL, A. BRUNET DEBAINES, A. TOUSSAINT, and R. KENT THOMAS. Extra crown 8vo, 6s. Also Pocket Edition, 2s. nett; leather, 3s. nett. Special yapp leather, full gilt, in box, 5s. nett.

LEE, SIDNEY.

Stratford-on-Avon. From the Earliest Times to the Death of Shakespeare. With Twelve Copper Plates and many other Illustrations. Super-royal 4to, 21s. Pocket Edition, 2s. nett; leather, 3s. nett; and in special yapp leather, full gilt, in box, 5s. nett.

LEFROY, W. CHAMBERS.

The Ruined Abbeys of Yorkshire. With many Illustrations by A. BRUNET-DEBAINES and H. TOUSSAINT. Crown 8vo, 6s.

LEGROS, ALPHONSE.

Six Etchings by Alphonse Legros. With a Biographical Note. Imperial 4to, 6s. nett.

LEYLAND, JOHN.

The Peak of Derbyshire. With Map, Etchings, and other Illustrations by HERBERT RAILTON and ALFRED DAWSON. Crown 8vo, 7s. 6d.

The Yorkshire Coast and the Cleveland Hills and Dales. With Etchings and other Illustrations. Crown 8vo, 7s. 6d.

LOFTIE, Rev. W. J.

The Inns of Court and Chancery. With many Illustrations, chiefly by HERBERT RAILTON. Crown 8vo, 6s.; and a New and Cheaper Edition, cloth, 2s. nett; leather, 3s.; and special yapp leather, in box, 5s. nett.

Westminster Abbey. With Seventy-four Illustrations, chiefly by HERBERT RAILTON. Large crown 8vo, 7s. 6d.

Whitehall. With many Illustrations. Super-royal 8vo, sewed, 2s. 6d. nett; half-linen, 3s. 6d. nett.

MACKENZIE, Rev. W. B.

Married Life and the Dwellings of the Righteous. 3s. 6d.; white silk, 7s. 6d.

The Word of Life. Crown 8vo, 3s. 6d.

MALLESON, Colonel G. B., C.S.I.

The Indian Mutiny. With Copper Plates and other Illustrations. Crown 8vo, 5s.

The Refounding of the German Empire. With Portrait and Plans. Crown 8vo, 5s.

MARCHANT, E. C., and LEWIS SERGEANT.

English Prose Composition. Part I. The Sentence. Crown 8vo, 2s.

MAYO, Miss.

Lessons on Objects. Fcap. 8vo, 3s. 6d.
Lessons on Shells. Fcap. 8vo, 3s. 6d.

McCARTHY, JUSTIN.

Charing Cross to St. Paul's. Illustrated by J. PENNELL. Crown 8vo, 6s.

MINIATURE LIBRARY OF DEVOTION

Little Volumes of Short Extracts from the Christian Fathers. With Decorative Title-pages and Photogravure Frontispiece. 32mo, cloth extra, each 1s. nett; leather, each 1s. 6d. nett. Also the Three Volumes in leather in case, 4s. 6d. nett.

Volumes now Ready:

1. **Saint Augustine.**
2. **Jeremy Taylor.**
3. **Saint Chrysostom.**

MITFORD, MARY RUSSELL.

Country Stories. With 68 Illustrations by GEORGE MORROW. Crown 8vo, cloth, gilt top, 2s. nett; also in leather, 3s. nett; and in special yapp leather, full gilt in box, 5s. nett.

MONKHOUSE, W. COSMO.

The Earlier English Water-Colour Painters. With many Illustrations. Crown 8vo, 6s.

MORIARTY, G. P.

Dean Swift. His Life and Writings. Cheaper Edition, with Two Portraits on Copper. 3s. 6d.

MOULE, Archdeacon A. E.

New China and Old. Notes on the Country and People made during a Residence of Thirty Years. With Thirty Illustrations. New Edition, Revised. Crown 8vo, 5s.

MOULE, Right Rev. H. C. G., D.D. (Bishop of Durham).

The Cross and the Spirit. Studies in the Epistle to the Galatians. Foolscap 8vo, 1s. 6d.

Grace and Godliness. Studies in the Epistle to the Ephesians. Crown 8vo, 2s. 6d.

At the Holy Communion. Helps for Preparation and Reception. Cloth, 1s.; leather, 2s. nett; calf, 4s. 6d.

In the House of the Pilgrimage. Hymns and Sacred Songs. 2s. 6d.

Imitations and Translations. Crown 8vo, 2s. 6d. nett.

Jesus and the Resurrection. Expository Studies on St. John xx. and xxi. Third Edition, 2s. 6d.

The Lord's Supper. By BISHOP RIDLEY. Edited with Notes and a Life by the BISHOP OF DURHAM. Crown 8vo, 5s.

Our Prayer Book. Short Chapters on the Book of Common Prayer. 16mo, 1s.; leather, 2s. nett.

The Pledges of His Love. Thoughts on the Holy Communion. 16mo, 1s.; leather, 2s. nett.

MOULE, Right Rev. H. C. G., D.D.—*Continued.*

Prayers for the Home. A Month's Cycle of Morning and Evening Family Worship, with some Occasional Prayers. Crown 8vo, 3s. 6d.

Prayers and Promises. Messages from the Holy Scriptures. 16mo, 1s.; leather, 2s. nett; calf, 4s. 6d.

Readings for a Month. With Five Illuminated Pages, and the Text printed in red and black. Crown 8vo, 5s. nett.

The Secret of the Presence, and other Sermons. Crown 8vo, 3s. 6d.

Temptation and Escape. Short Chapters for Beginners in the Christian Life. 16mo, 1s.; leather, 2s. nett.

Thoughts on Christian Sanctity. 16mo, cloth, 1s.; leather, 2s. nett.

Thoughts on Secret Prayer. 16mo, cloth, 1s.; leather, 2s. nett; calf, 4s. 6d.

Thoughts on the Spiritual Life. 16mo, cloth, 1s.; leather, 2s. nett.

Thoughts on Union with Christ. 16mo, cloth, 1s.; leather, 2s. nett.

MURRAY, A. S., LL.D.

Greek Bronzes. With Four Copper Plates and many other Illustrations. Super-royal 8vo, sewed, 3s. 6d. nett; cloth, 4s. 6d. nett.

Greek Bronzes and **Greek Terracotta Statuettes.** By C. A. Hutton. With Four Photogravures, Eight Coloured Plates, and Seventy-seven other Illustrations. In one Volume. Super-royal 8vo, cloth, 10s. 6d. nett.

NETTLESHIP, J. T.

Morland, George. With Six Copper Plates and Thirty other Illustrations. Super-royal 8vo, sewed, 5s. nett; cloth, 6s. nett.

PAGE, J. Ll. WARDEN.

Dartmoor, An Exploration of. With Map, Etchings, and other Illustrations. Third Edition. Crown 8vo, cloth, 7s. 6d. Cheap Edition, 3s. 6d.

Exmoor, An Exploration of. With Maps, Etchings, and other Illustrations. Third Edition. Crown 8vo, 7s. 6d. Cheap Edition, 3s. 6d.

The Rivers of Devon. From Source to Sea. With Map, Etchings, and other Illustrations. Third Edition. Crown 8vo, 7s. 6d.

PALMER, SAMUEL.

The Eclogues of Virgil. An English Version. With Fourteen Copper Plates by the Author. Imperial 4to, 21s.

The Minor Poems of John Milton. With Twelve Copper Plates after Samuel Palmer. Imperial 4to, 21s.

PENNELL, J. and E.

A Canterbury Pilgrimage. Pott 4to, cloth, gilt edges, 2s. 6d.

PHILLIPS, CLAUDE.

The Earlier Work of Titian. With many Illustrations. Super-royal 8vo, sewed, 3s. 6d. nett.

The Later Work of Titian. With many Illustrations. Super-royal 8vo, sewed, 3s. 6d. nett.

Titian, a Study of his Life and Work. With Eight Copper Plates and many other Illustrations. Super-royal 8vo, 9s. nett.

The Picture Gallery of Charles I. With many Illustrations. Super-royal 8vo, sewed, 3s. 6d. nett.

Sir Joshua Reynolds. Cheaper Edition with Two Portraits on Copper, 3s. 6d.

PHILLIPS, CLAUDE—*Continued.*

Frederick Walker. With many Illustrations. Super-royal 8vo, sewed, 2s. 6d. nett; half-linen, 3s. 6d. nett.

Antoine Watteau. With many Illustrations. Super-royal 8vo, sewed, 2s. 6d. nett; half-linen, 3s. 6d. nett.

POLLARD, A. W.

Italian Book Illustrations. With many Illustrations. Super-royal 8vo, sewed, 2s. 6d.; half-linen, 3s. 6d. nett.

PORTFOLIO MONOGRAPHS ON ARTISTIC SUBJECTS

"A triumph of magnificent illustration and masterly editing."—*The Times.*

NEW VOLUME. JUST PUBLISHED.

THE CATHEDRAL BUILDERS OF ENGLAND.

By E. S. PRIOR, F.S.A.

With many Illustrations, some in colours. Super-royal 8vo, 5s. nett, and in cloth, 7s. nett.

Many of the Volumes are issued in two forms and at various nett prices. Where two prices are given, the first is that of the paper cover edition; the second that of the cloth. When only one price is given, the Volume is bound in paper only.

ANDERSON, Prof. W.

Japanese Wood Engravings. 2s. 6d. and 3s. 6d.

ARMSTRONG, Sir WALTER.

The Art of Velazquez. 3s. 6d.
The Life of Velazquez. 3s. 6d.
The Peel Collection and the Dutch School of Painting. 5s. and 7s.
Thomas Gainsborough. Half-linen, 3s. 6d.
W. Q. Orchardson. 2s. 6d. and 3s. 6d.

BEDFORD, W. K. R.

Malta. 2s. 6d. and 3s. 6d.

BENHAM, Canon, and CHARLES WELCH, F.S.A.

Mediæval London. 5s. and 7s.

BENHAM, Canon.

Old St. Paul's Cathedral. 5s. and 7s.

BINYON, LAURENCE.

Dutch Etchers of XVIIth Century. 2s. 6d. and 3s. 6d.
John Crome and J. S. Cotman. 3s. 6d.

BIRCH, G. H., F.S.A.

London on Thames. 5s. and 7s.

CARTWRIGHT, JULIA (Mrs. ADY).

Jules Bastien-Lepage. 2s. 6d. and 3s. 6d.
The Early Work of Raphael. 2s. 6d. and 3s. 6d.
Raphael in Rome. 2s. 6d. and 3s. 6d.

CHURCH, A. H., F.R.S.

Josiah Wedgwood. 5s. and 7s.

CORNISH, C. J.
The Isle of Wight. 2s. 6d. and 3s. 6d.
The New Forest. 2s. 6d. and 3s. 6d.

CUST, LIONEL, F.S.A.
The Engravings of Albert Dürer. 2s. 6d. and 3s. 6d.
The Paintings and Drawings of Albert Dürer. 3s. 6d.

DAVENPORT, CYRIL, F.S.A.
Royal English Bookbindings. 3s. 6d. and 4s. 6d.
Cameos. 5s. and 7s.

DESTRÉE, O. G.
The Renaissance of Sculpture in Belgium. 2s. 6d. and 3s. 6d.

FLETCHER, W. Y.
Bookbinding in France. 2s. 6d. and 3s. 6d.

GARDNER, J. STARKIE.
Armour in England. 3s. 6d.
Foreign Armour in England. 3s. 6d.

GARNETT, RICHARD, C.B., LL.D.
William Blake. 2s. 6d. and 3s. 6d.
Richmond on Thames. 3s. 6d. and 4s. 6d.

GRAHAME, GEORGE.
Claude Lorrain. 2s. 6d. and 3s. 6d.

HAMERTON, P. G.
The Etchings of Rembrandt. 2s. 6d. and 3s. 6d.

HUTTON, C. A.
Greek Terracotta Statuettes. 3s. 6d. and 4s. 6d.

LOFTIE, W. J.
Whitehall. 2s. 6d. and 3s. 6d.

MURRAY, A. S., LL.D.
Greek Bronzes. 3s. 6d. and 4s. 6d.

NETTLESHIP, J. T.
George Morland. 5s. and 6s.

PHILLIPS, CLAUDE.
Frederick Walker. 2s. 6d. and 3s. 6d.
Antoine Watteau. 2s. 6d. and 3s. 6d.
The Picture Gallery of Charles I. 3s. 6d.
The Earlier Work of Titian. 3s. 6d.
The Later Work of Titian. 3s. 6d.

POLLARD, ALFRED W.
Italian Book Illustrations. 2s. 6d. and 3s. 6d.

SHARP, WILLIAM.
Fair Women. 2s. 6d. and 3s. 6d.

STEPHENS, F. G.
Dante Gabriel Rossetti. 2s. 6d. and 3s. 6d.

STEVENSON, R. A. M.
Peter Paul Rubens. 3s. 6d.

WAERN, CECILIA.
John La Farge. 3s. 6d.

WEALE, W. H. JAMES.
Gerard David, Painter and Illuminator. 2s. 6d. and 3s. 6d.

PRIOR, E. S., F.S.A.
The Cathedral Builders of England. Illustrated. Super-royal 8vo, sewed, 5s. nett; cloth, extra gilt top, 7s. nett.

PRUEN, S. T.
The Arab and the African. With Illustrations. Crown 8vo, 3s. 6d.

RAJON, PAUL.
Twelve Etchings by. With Memoir. Imperial 4to, cloth, 21s.

REYNOLDS, Sir JOSHUA.
Discourses Delivered to the Students of the Royal Academy. With an Introduction and Notes by ROGER FRY. With Thirty-Three Illustrations. Square Extra Crown 8vo, 7s. 6d. nett.

RIDLEY, Bishop.
Not Myth but Miracle. A Poem. 1s. 6d.
My Favourite Avenues. Poems. 2s. 6d. nett.

ROPES, A. R.
Lady Mary Wortley Montagu. With Nine Copper Plates. Crown 8vo, cloth, 7s. 6d.

RUSSELL, W. CLARK.
The British Seas. With upwards of Fifty Illustrations. Crown 8vo, 6s. And New and Cheaper Edition. Cloth, 2s.; leather, 3s.; special yapp leather in box, 5s. nett.

SANDBY, W.
Thomas and Paul Sandby, Royal Academicians. Their Lives and Works. With many Illustrations. Crown 8vo, 7s. 6d.

SANDERSON, E.
Africa in the Nineteenth Century. With Four Portraits on Copper and a Map. Crown 8vo, 5s.

SARGENT, Rev. J.
Henry Martyn, Life and Letters. Crown 8vo, 2s. 6d.

SEELEY'S ILLUSTRATED POCKET LIBRARY

Crown 8vo, cloth, gilt edge, 2s. nett; also in leather, 3s. nett; and yapp leather in box at 5s.

ADDISON and STEELE.
The Spectator in London. With Fifty-six Illustrations by RALPH CLEAVER, and Headpieces by W. A. ATKIN BERRY, CLOUGH BROMLEY, &c.

LEE, SIDNEY.
Stratford-on-Avon. From the Earliest Times to the Death of Shakespeare. With 52 Illustrations by HERBERT RAILTON and E. HULL.

MITFORD, MARY RUSSELL.
Country Stories. With 68 Illustrations by GEORGE MORROW.

Seeley & Co Limited

HERBERT, GEORGE.

The Temple. Sacred Poems and Ejaculations. The Text reprinted from the first edition. With Seventy-six Illustrations after Albert Dürer, Holbein, and other Masters.

LANG, ANDREW.

Oxford. With 40 Illustrations by various artists.

LOFTIE, W. J.

The Inns of Court. With 60 Illustrations.

RUSSELL, W. CLARK.

British Seas. With 50 Illustrations by J. C. Hook, R.A., Hamilton MacCallum, Colin Hunter, &c.

STEVENSON, R. L. Edinburgh. With many Illustrations by T. Hamilton Crawford, R.S.A. (This volume is only to be had in this series in leather, 5s. nett. For other editions of this book, see below.)

SEELEY, Sir J. R.

Goethe Reviewed after Sixty Years. With Portrait. Crown 8vo, 3s. 6d.

A Short History of Napoleon the First. With Portrait. Crown 8vo, 5s.

SEELEY, Sir J. R., and Dr. ABBOTT.

English Lessons for English People. Crown 8vo, 4s. 6d.

SEELEY, L. B.

Mrs. Thrale, afterwards Mrs. Piozzi. With Nine Copper Plates Crown 8vo, 7s. 6d.

Horace Walpole and his World. Extracts from his Letters. With Eight Copper Plates. Crown 8vo, 7s. 6d.

Fanny Burney and her Friends. With Nine Copper Plates. Crown 8vo, 7s. 6d.

SHAND, A. INNES.

General John Jacob. Commander of the Sind Irregular Horse, and Founder of Jacobabad. With many Illustrations. Demy 8vo, 6s.

The War in the Peninsula. With Portraits and Plans. 5s.

SHARLAND, E. CRUWYS.

The Story Books of Little Gidding: Being the Religious Dialogues recited in the Great Room at Little Gidding Hall, 1631–2. From the Original Manuscript of Nicholas Ferrar. With an Introduction by E. Cruwys Sharland, and several Illustrations. Crown 8vo, 6s.

SHARP, WILLIAM.

Fair Women. Illustrated. Super-royal 8vo, sewed, 2s. 6d. nett.; half-linen, 3s. 6d. nett.

SHIPLEY, M. E.

Daily Help for Daily Need. A Selection of Scripture Verses and Poetry for Every Day in the Year. Crown 8vo, 4s. 6d.

STEPHENS, F. G.

Rossetti, D. G. Super-royal 8vo, sewed, 2s. 6d. nett; half-linen, 3s. 6d. nett.

STEVENSON, R. L.

Edinburgh. Fcap. 8vo, with Frontispiece, gilt top, cloth, 2s. nett; leather, 3s. nett. Crown 8vo, Illustrated, cloth, 3s. 6d. Roxburgh, gilt top, 5s. Buckram, dark blue, gilt top, 16 Full-page Illustrations, 6s. Royal 8vo, gilt top, with Four Copper Plates, and many other illustrations by T. Hamilton Crawford, R.S.W., 7s. 6d. nett. Roxburgh, gilt top, Eight Copper Plates, and many other Illustrations by T. H. Crawford, 16s. nett.

STEVENSON, R. A. M.
Rubens, Peter Paul. Illustrated. Super-royal 8vo, 3s. 6d. nett, sewed.

STRANG, WILLIAM.
Six Etchings. By D. Y. CAMERON and WILLIAM STRANG. With Biographical Notes. Imperial 4to, 6s. nett.

SUMNER, HEYWOOD.
The Avon from Naseby to Tewkesbury. Twenty-one Etchings. Imperial 4to, 31s. 6d.
The Itchen Valley. From Tichborne to Southampton. Twenty-two Etchings. Imperial 4to, 31s. 6d.

WACE, Very Rev. H., Dean of Canterbury.
The Sacrifice of Christ. Its Vital Reality and Efficacy. Cloth, 1s.

WAERN, C.
John La Farge. Illustrated. Super-royal 8vo, sewed, 3s. 6d. nett.

WEALE, W. H. JAMES.
Gerard David, Painter and Illuminator. Illustrated. Super-royal 8vo, sewed, 2s. 6d. nett; half-linen, 3s. 6d. nett.

WELCH, C., and Canon BENHAM.
Mediæval London. With a Frontispiece in Photogravure, Four Plates in Colour, and many other Illustrations. Super-royal 8vo, sewed, 5s. nett; cloth, gilt top, 7s. nett.

WELLDON, Bishop.
The Hope of Immortality. An Essay. Third and Cheaper Edition. Crown 8vo, 3s. 6d.

WHATELY, M. L.
Letters from Egypt. With Illustrations. 3s. 6d.

WILKINSON, Rev. D. H. D.
Baptism: What Saith the Scripture? With a Preface by the BISHOP OF DURHAM. Foolscap 8vo, 1s. 6d.

WORNUM, R. N.
The National Gallery. With Eighteen Plates. Large 4to, 31s. 6d.
——— Second Series. With Eighteen Plates. 31s. 6d.

WRITERS AND PAINTERS OF THE EIGHTEENTH CENTURY

Lady Mary Wortley Montagu. By A. R. ROPES. With Nine Copper Plates. Crown 8vo, 7s. 6d.

Mrs. Thrale, afterwards Mrs. Piozzi. By L. B. SEELEY. With Nine Copper Plates. Crown 8vo, 7s. 6d.

Horace Walpole and his World. Extracts from his Letters. Edited by L. B. SEELEY. With Eight Copper Plates. Crown 8vo, 7s. 6d.

Fanny Burney and her Friends. By L. B. SEELEY. With Nine Copper Plates. Crown 8vo, 7s. 6d.

Dean Swift. His Life and Writings. By GERALD P. MORIARTY, Balliol College, Oxford. Cheaper Edition, with Two Portraits on Copper. 3s. 6d.

Sir Joshua Reynolds. By CLAUDE PHILLIPS, Keeper of the Wallace Collection at Hertford House. Cheaper Edition with Two Portraits on Copper. 3s. 6d.